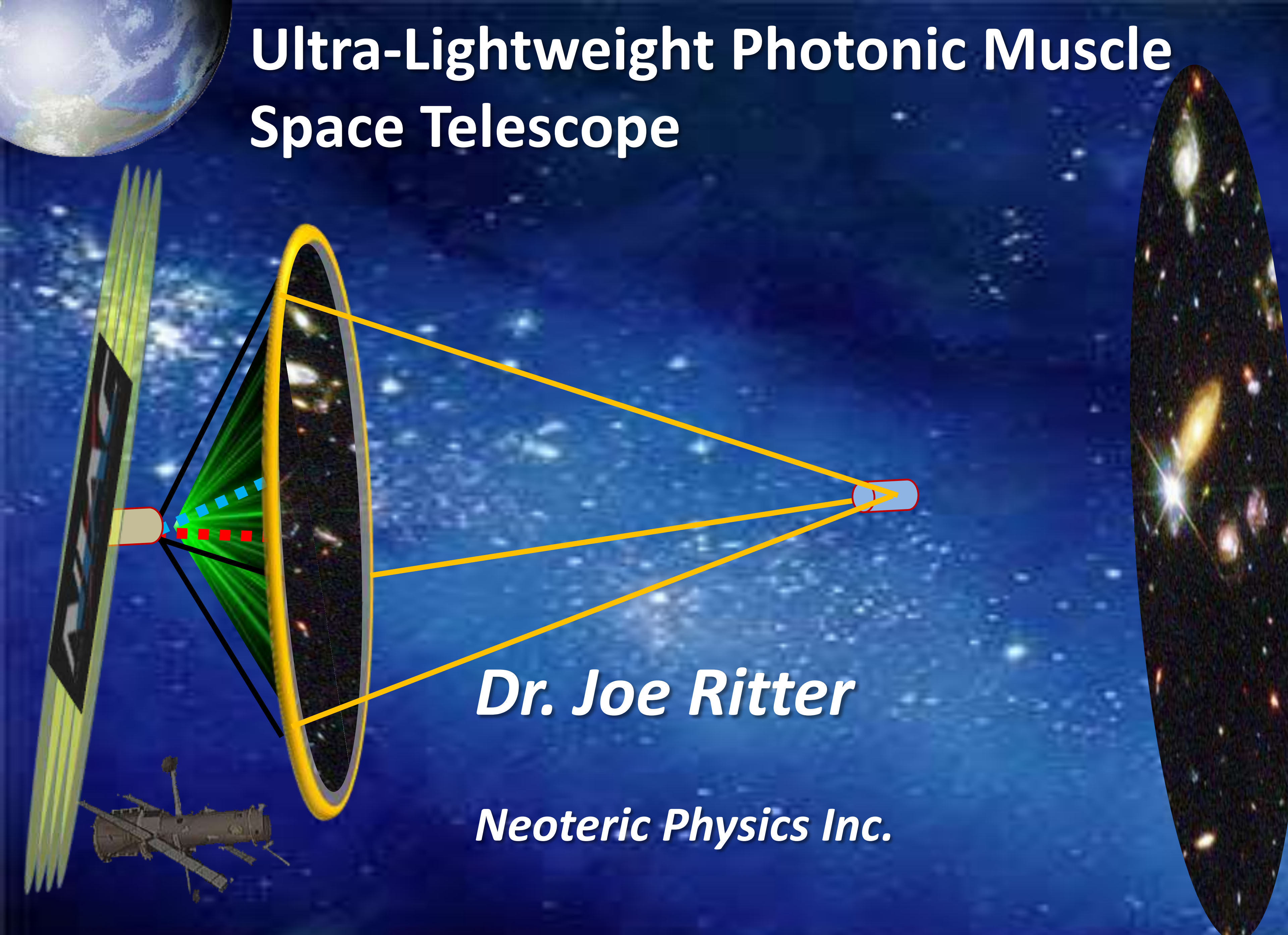
Ultra-Lightweight Photonic Muscle Space Telescope



Dr. Joe Ritter

Neoteric Physics Inc.

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Tools







- The advancement of science=f(Tools)
- Tools=f(materials)
- Stone age-2.5 million years
- ended 4500-2000 BC with advent of metalworking BECAUSE ofBronze age
- 60 years ago Semiconductors, then lasers
- Now Photonics and Meta-materials- New age

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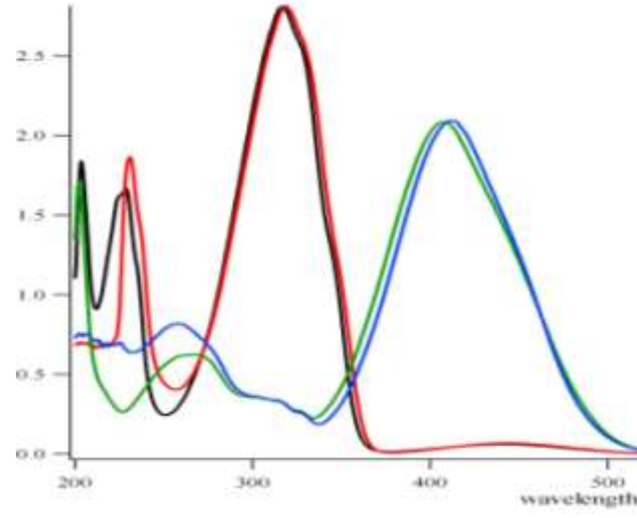
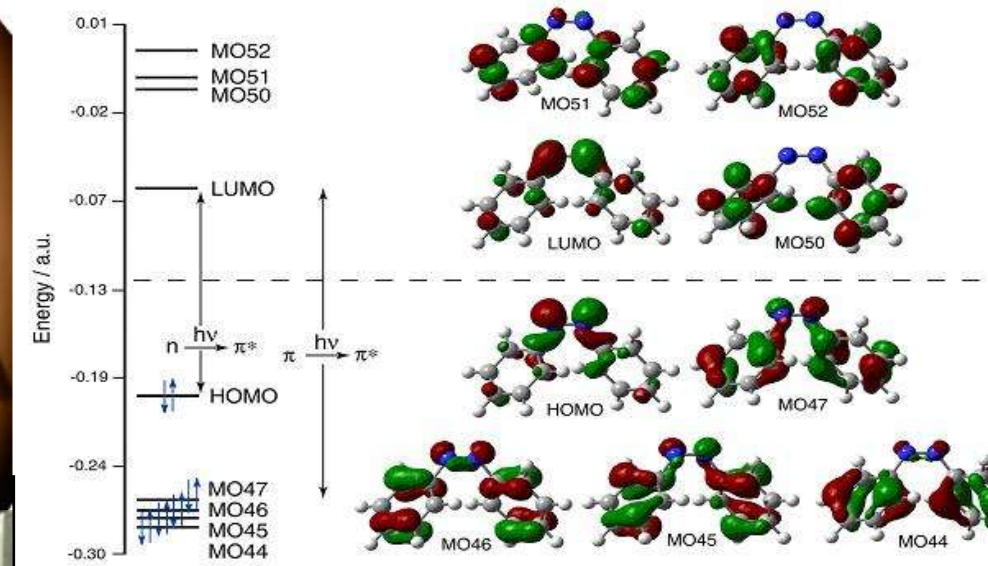
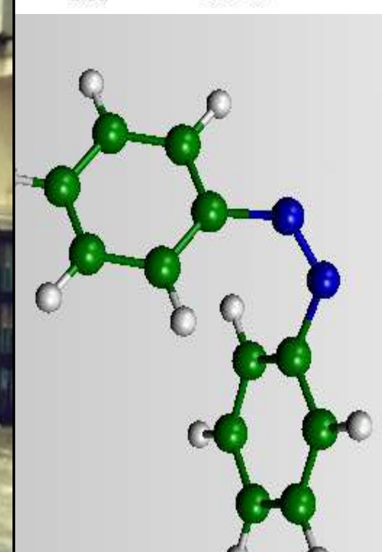
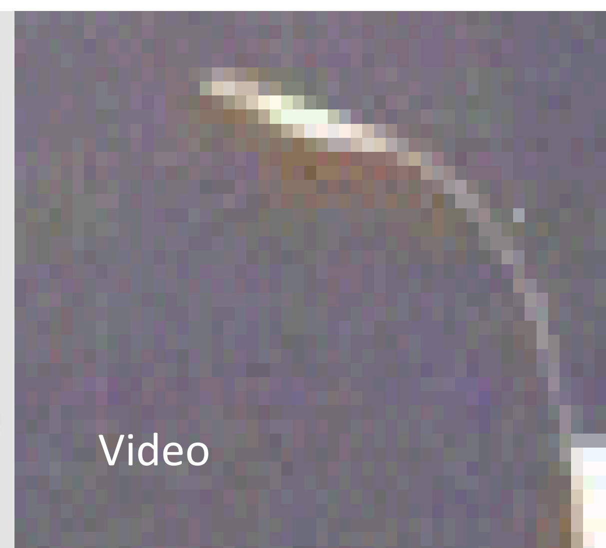
On the subject of tools for science and exploration…
Here is how to build an *Inexpensive Giant Telescope*









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Photons weigh nothing

Q:Why must even small space telescopes weigh tons? (or require high mass…)

- **A:Telescopes require sub-wavelength figure (shape) error in order to achieve acceptable Strehl ratios.**

- **Traditional methods of achieving this require expensive long grinding, rigid and therefore heavy mirrors and reaction structures as well as proportionally expensive spacecraft busses and launch vehicles.**

- **Using novel optically controlled molecular actuators will allow the substitution of optically induced control for rigidity and mass. (Factor of >>100 Improvement)**

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Why develop optically controlled active optics?

Specific goals

- Enable larger apertures 2 reasons : $\theta \sim \lambda / D$ $A = \pi r^2$
- Enable factor of 100 reduction in mirror areal density
- Reduce telescope fabrication cost 20x
- Reduce launch mass and costs 10x

Grand Challenges:

Find life, understand formation of universe exploration of exoplanets….

Other applications: Proprietary content

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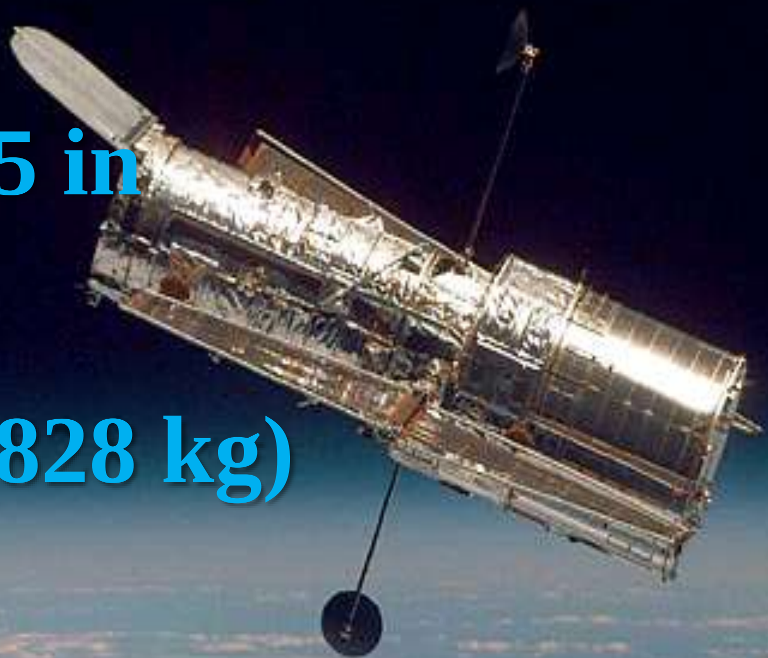
History-HST Mirror:<8 foot diameter, not active optics

HST: one of the greatest tools ever built



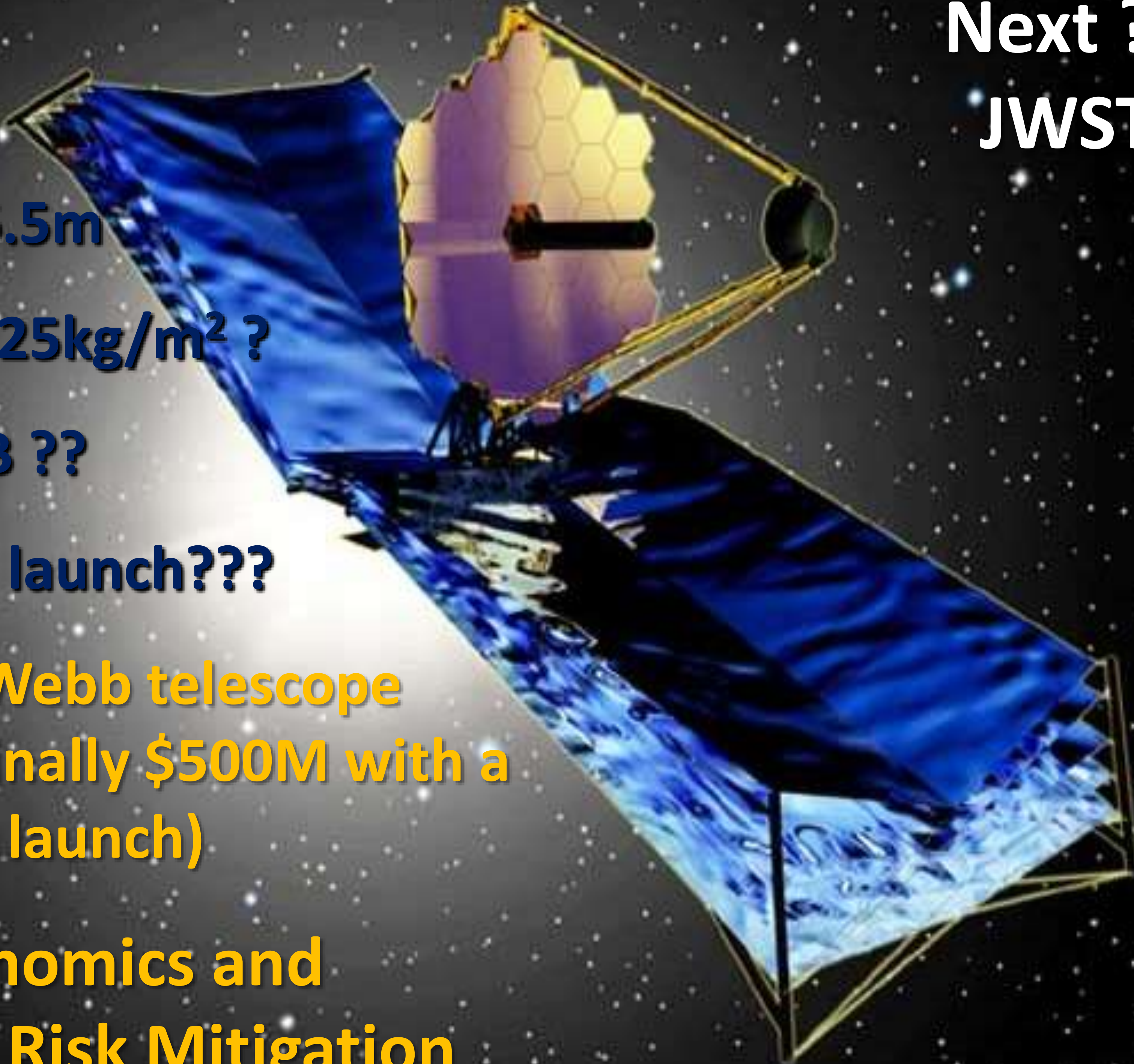
M1 Diameter: 94.5 in (2.4 m)

Weight: 1,825 lb (828 kg)

180kg/m^2

$2B

Next ??
JWST



M1:6.5m

m/A:25kg/m^2 ?

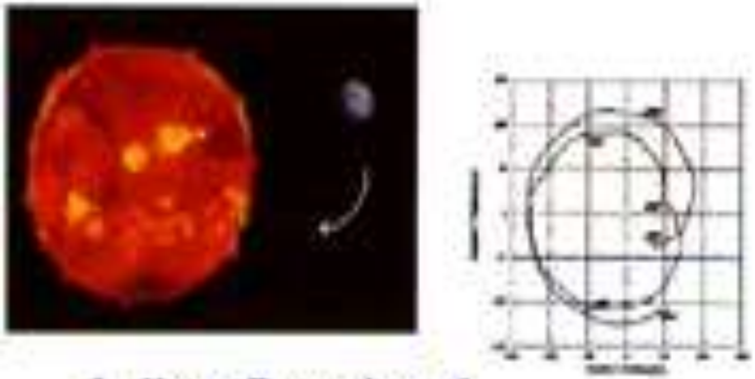
$8.7B ??

2018 launch???

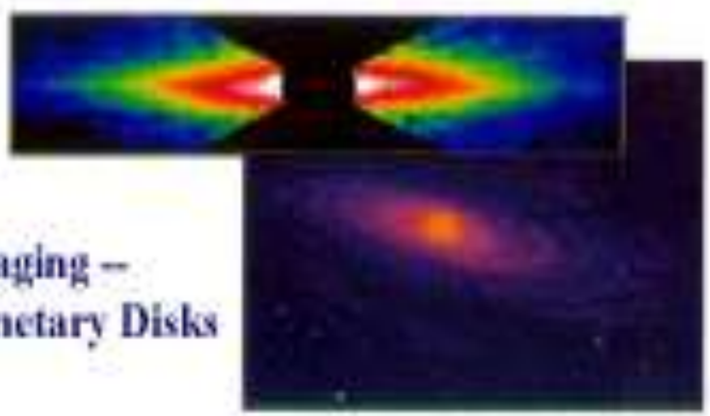
The Webb telescope (originally $500M with a 2011 launch)

.Economics and
Risk Mitigation

Examples of (scrapped) potential missions: Space Interferometry Mission



Indirect Detection of
Planets through Observations
of Thousands of Stars

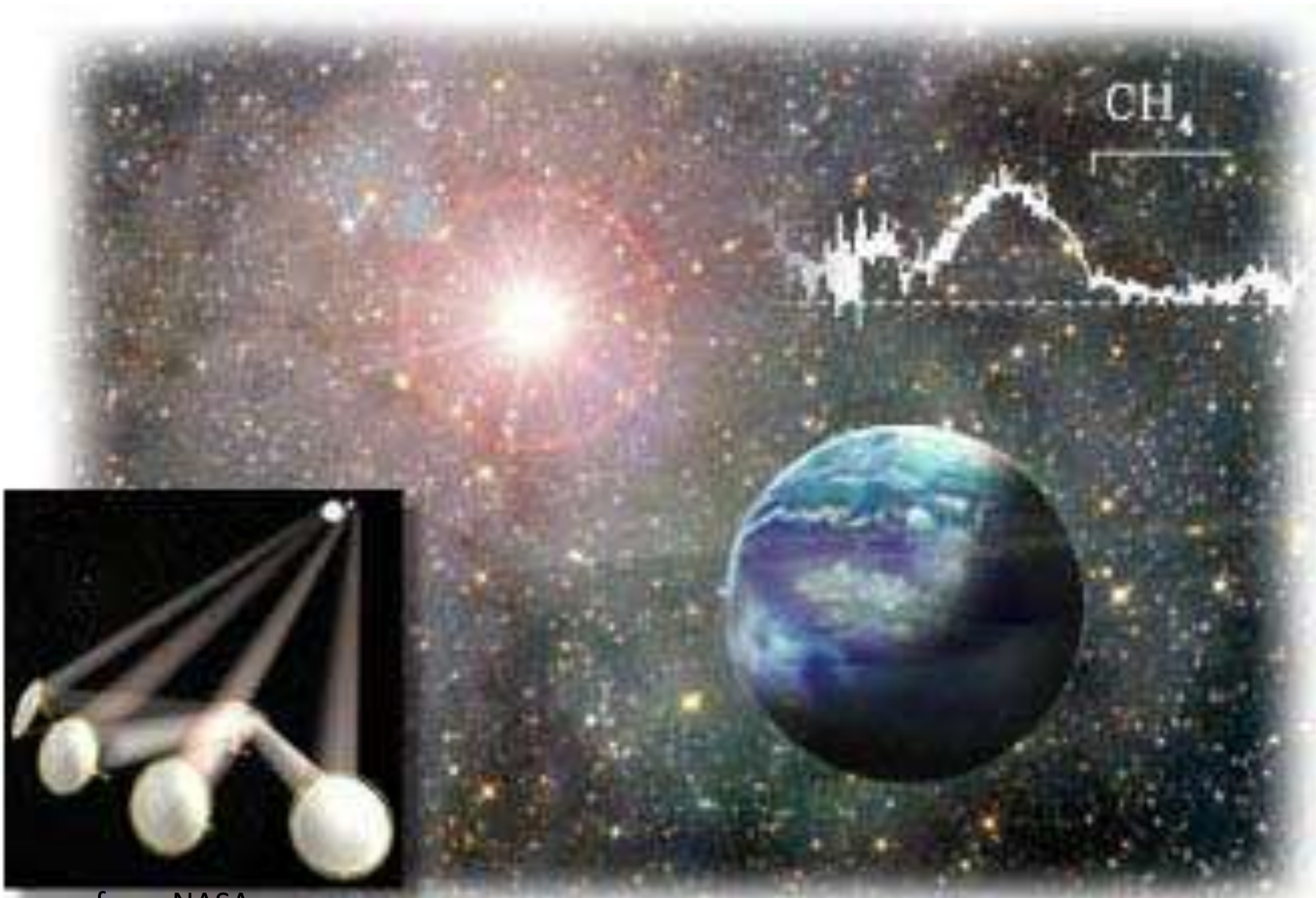


Nulling Imaging --
Structure of Planetary Disks

High Resolution Imaging --
5 Times Better than HST on
a Small Field of View

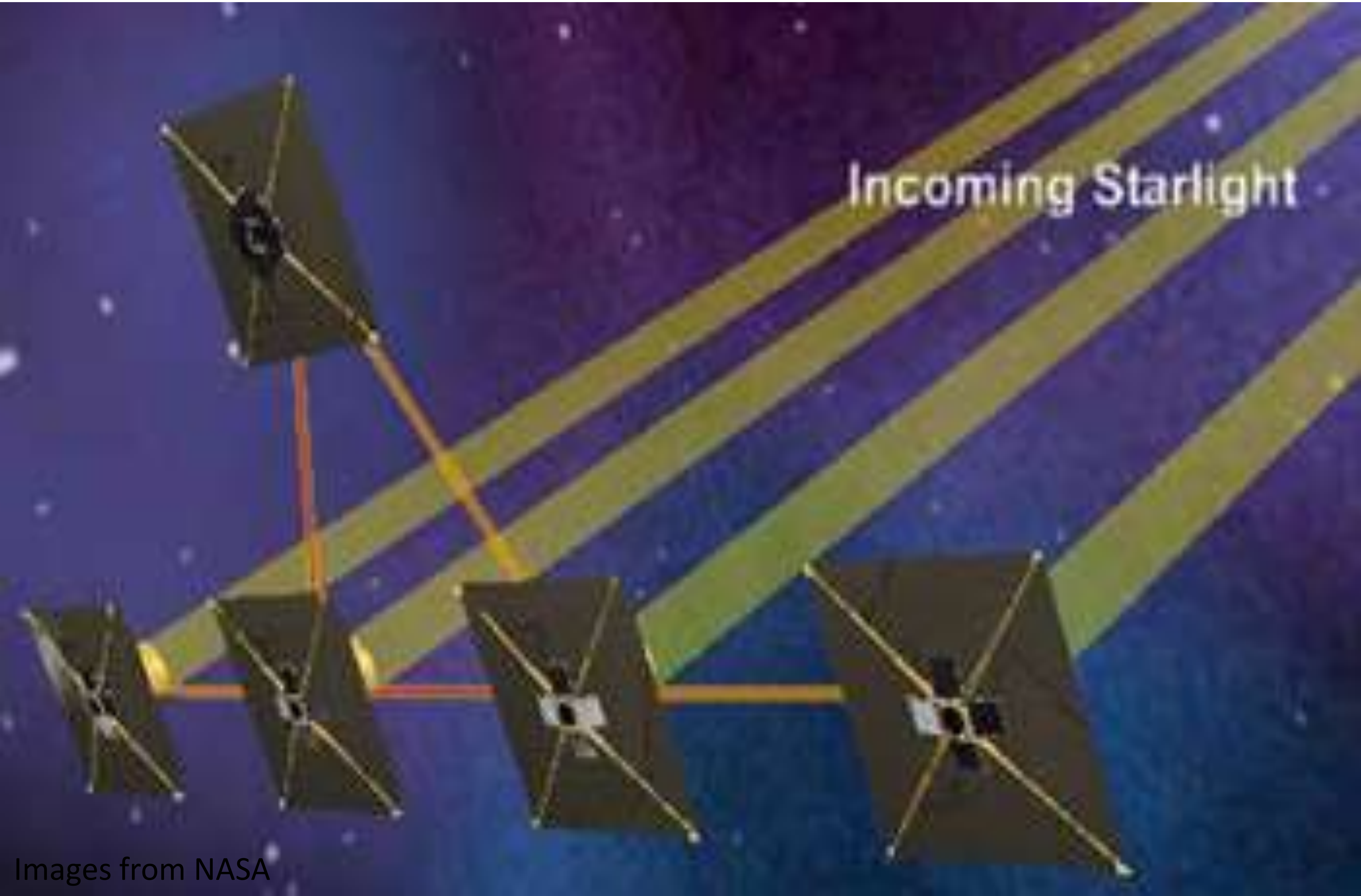
Images from NASA

Life Finder (not happening)



Images from NASA

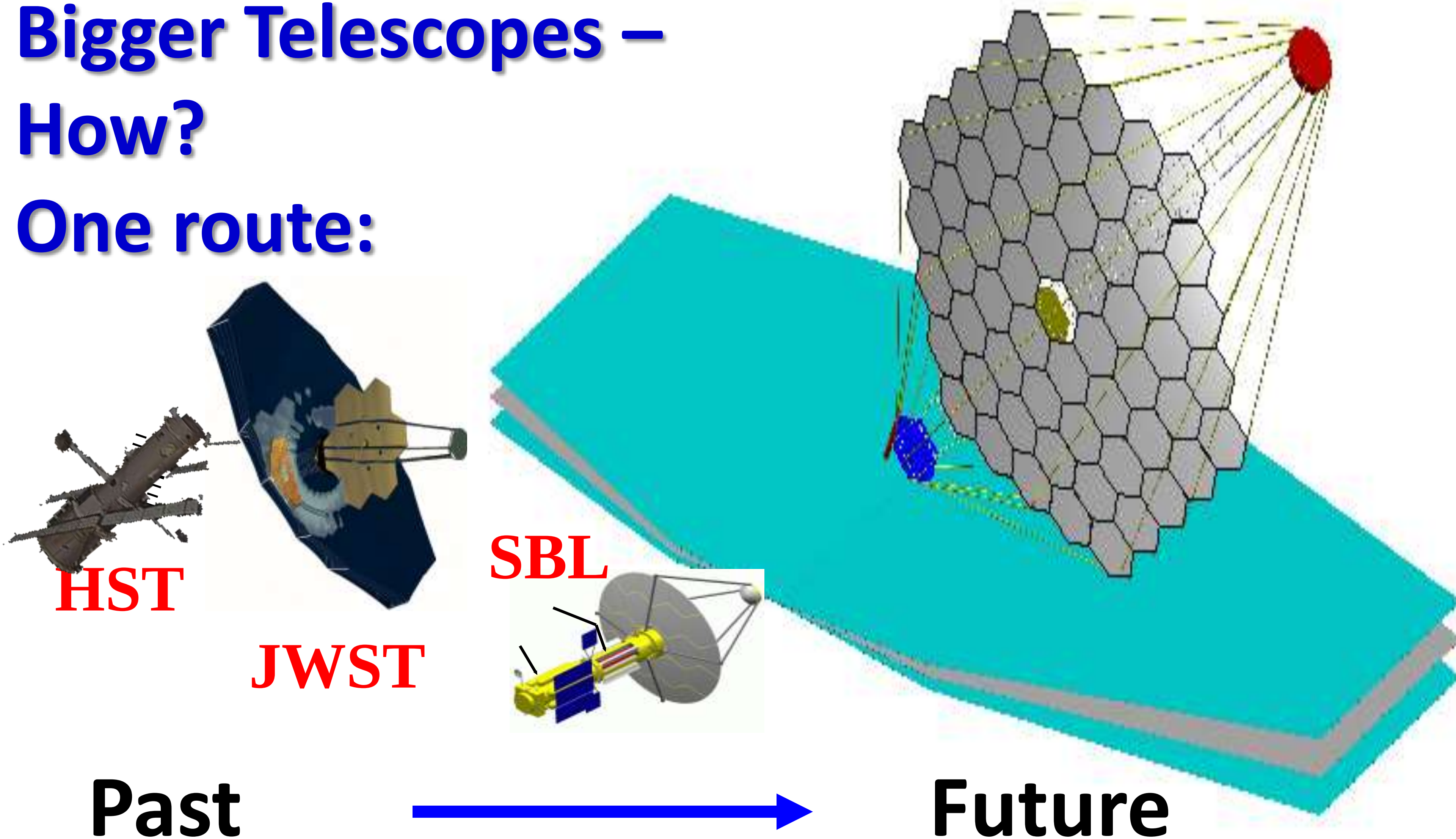
TPI (terrestrial planet imager) Array



Images from NASA

Bigger Telescopes – How?

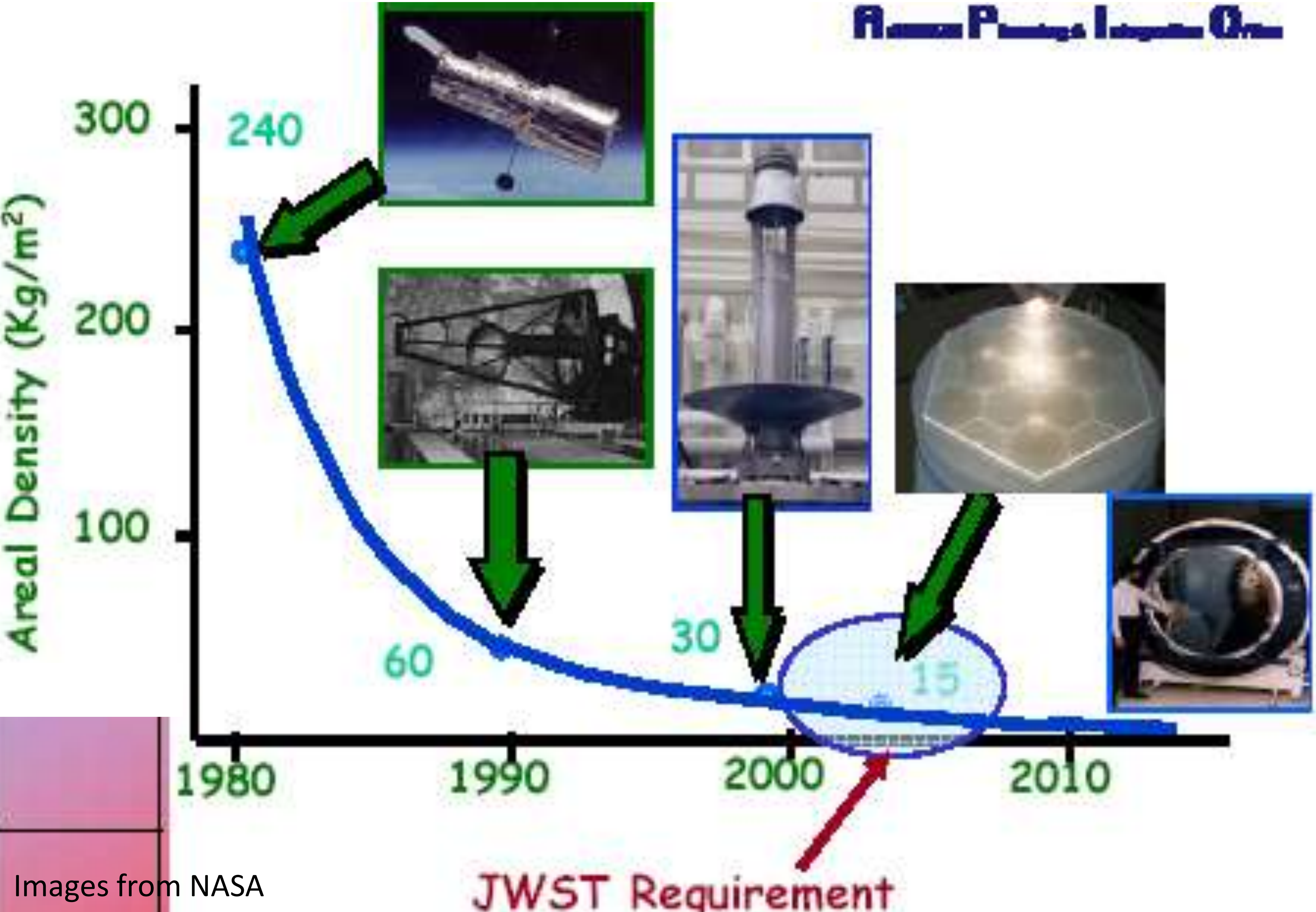
One route:



- Segmentation? =Brute force

- Actuation? =Elegant

Space Telescopes: Areal Density vs. Time

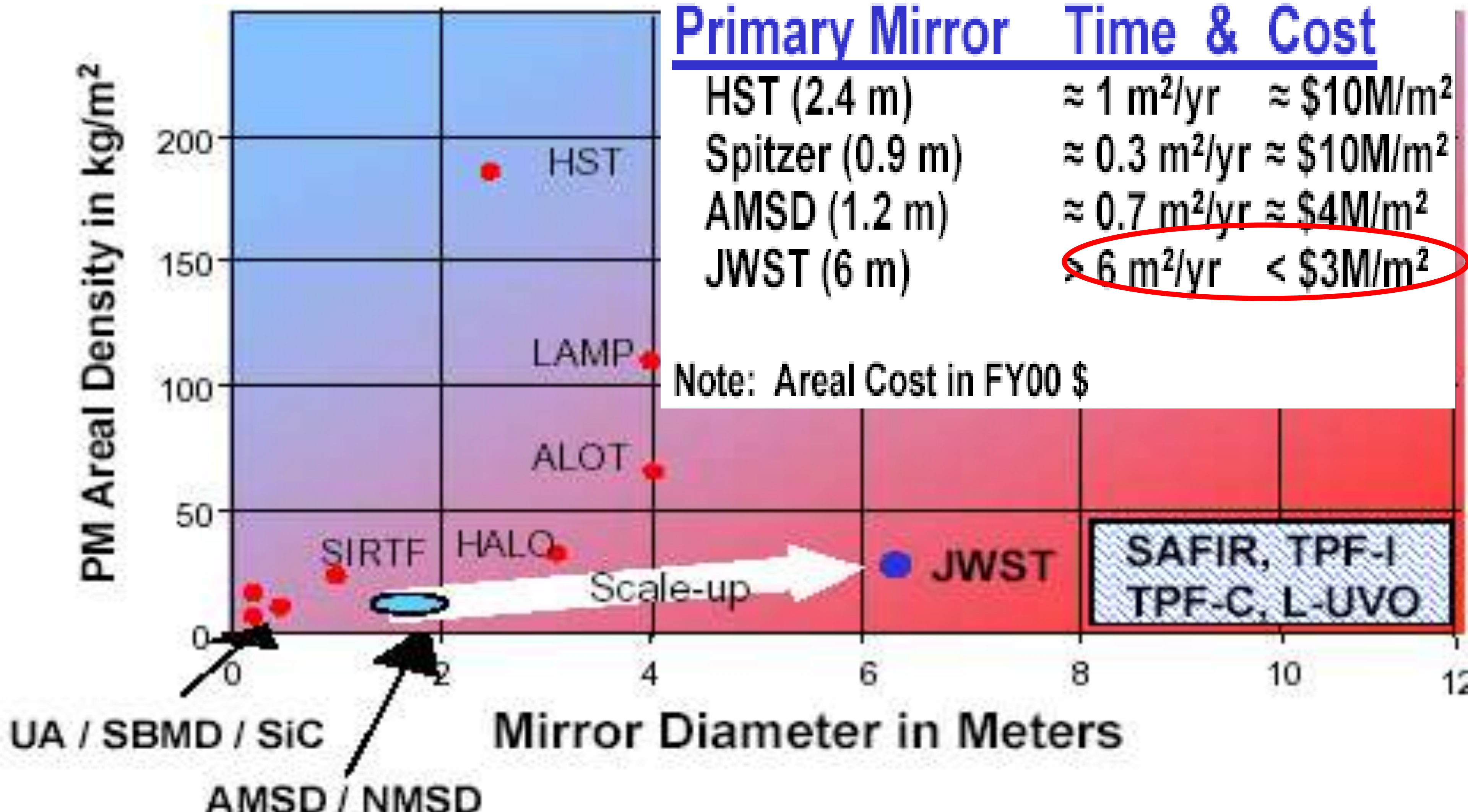


Images from NASA

How it is done now:

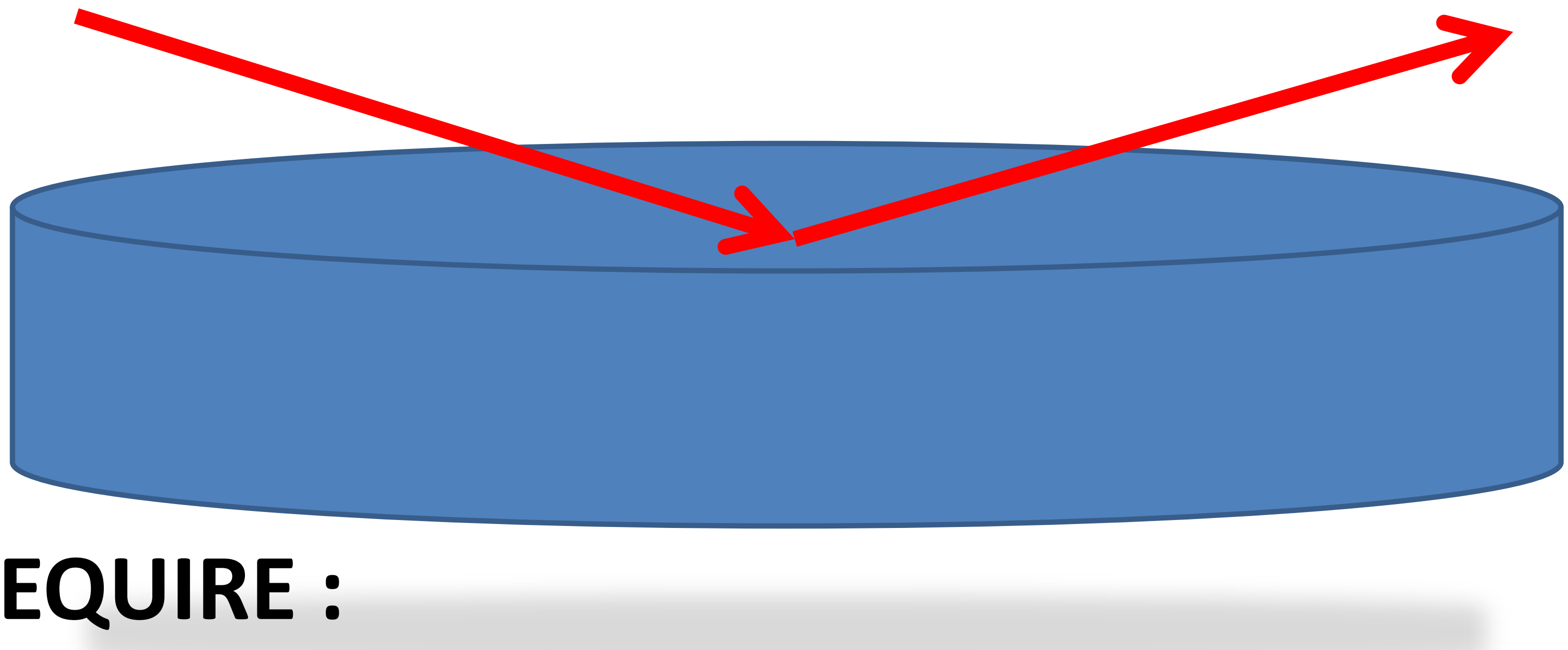
from NASA Advanced Telescope and Observatories Capability Roadmap. Cost not current:

Mirrors are expensive and slow to make



How to make an ultra-lightweight mirror:

Tradespace- mirror actuation primer

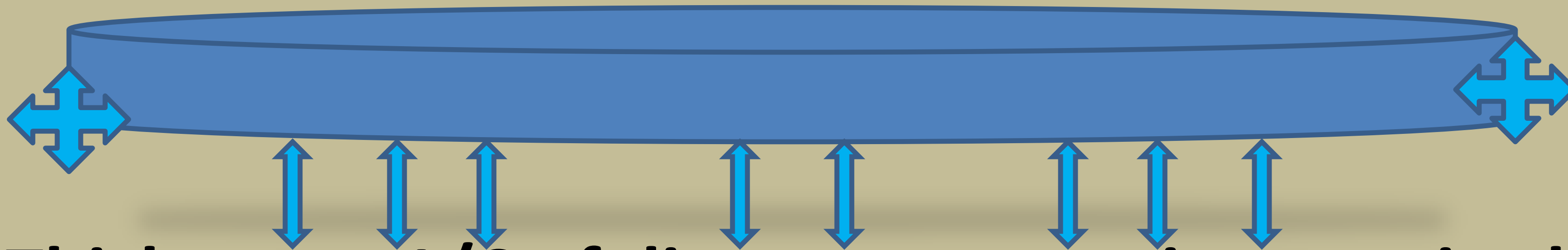


- **REQUIRE :**

  Optical figure tolerance human hair D/1000

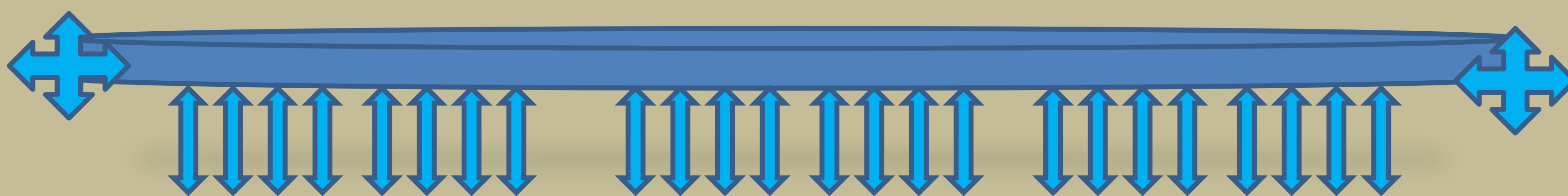
- **For glass, Thickness = 1/6 of diameter**
- **<u>no actuation required</u> (no figure control)**

Mirror actuation



- Thickness < 1/6 of diameter, actuation required

  This is “Active optics”



- Can be thinner requires more actuators to maintain shape

- Obvious design trade space limit:

  infinitely thin with an infinite number of actuators!

- Can this be done ?   Is there a sweet spot?

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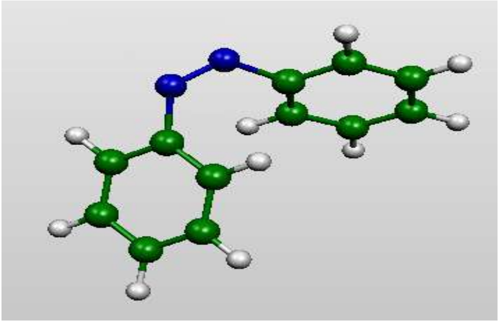
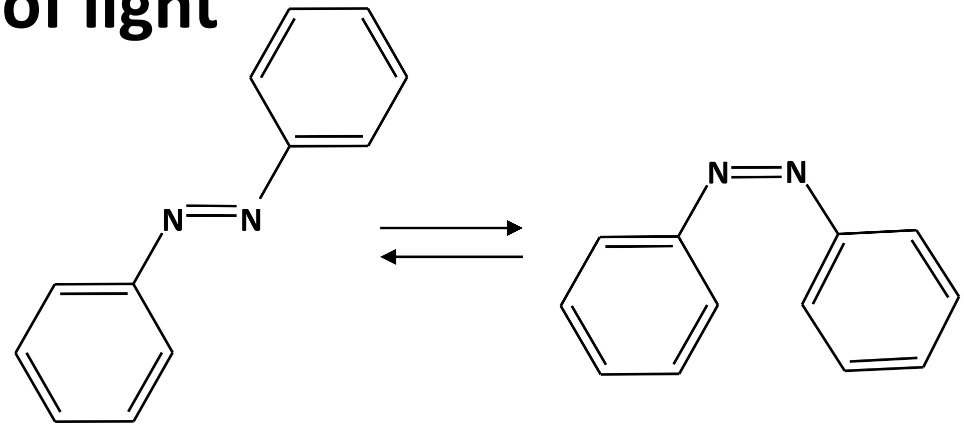
How Does a Photonic Muscle Work?

The chromophore molecule azo-benzene has two isomer structures; "*Cis*" and "*Trans*", which can be switched by using specific wavelengths of light



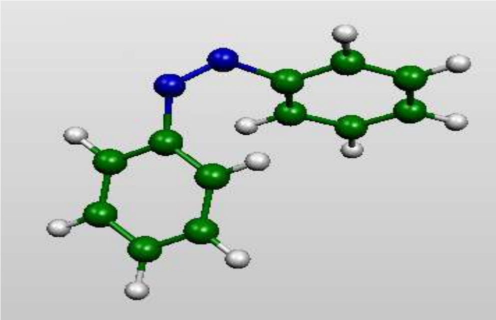


Some Azobenzene moieties undergo *Cis-Trans* photoisomerization, a reversible reorganization of molecular structure induced by light, which is accompanied by a change in the overall shape and volume of the molecule.

Induced strain is over 40% !

Forces are pico-newtons/molecule.

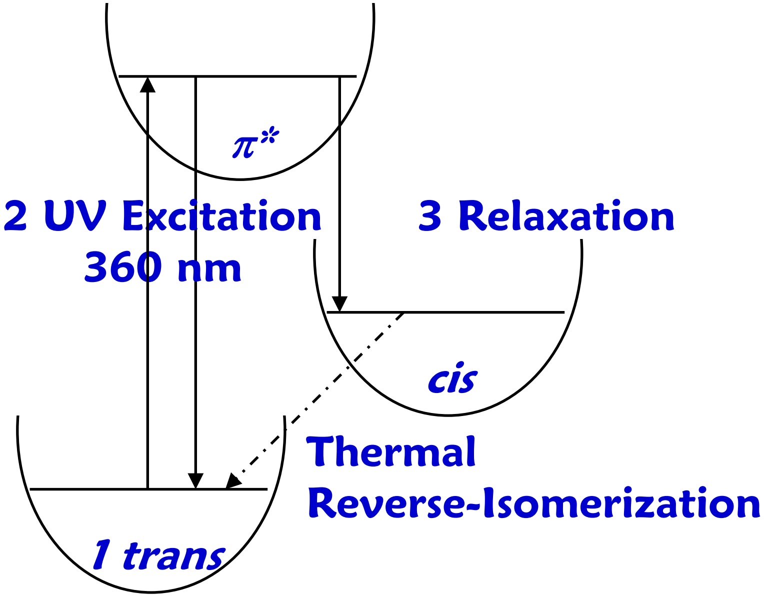
Photoisomerization Theory



1. UV irradiation: π–π^* electronic transition
   1. Azo bond order decreased from 2 to 1

2. Rotation at azo bond in the excited (photolyzed) state causes interconversion between isomers

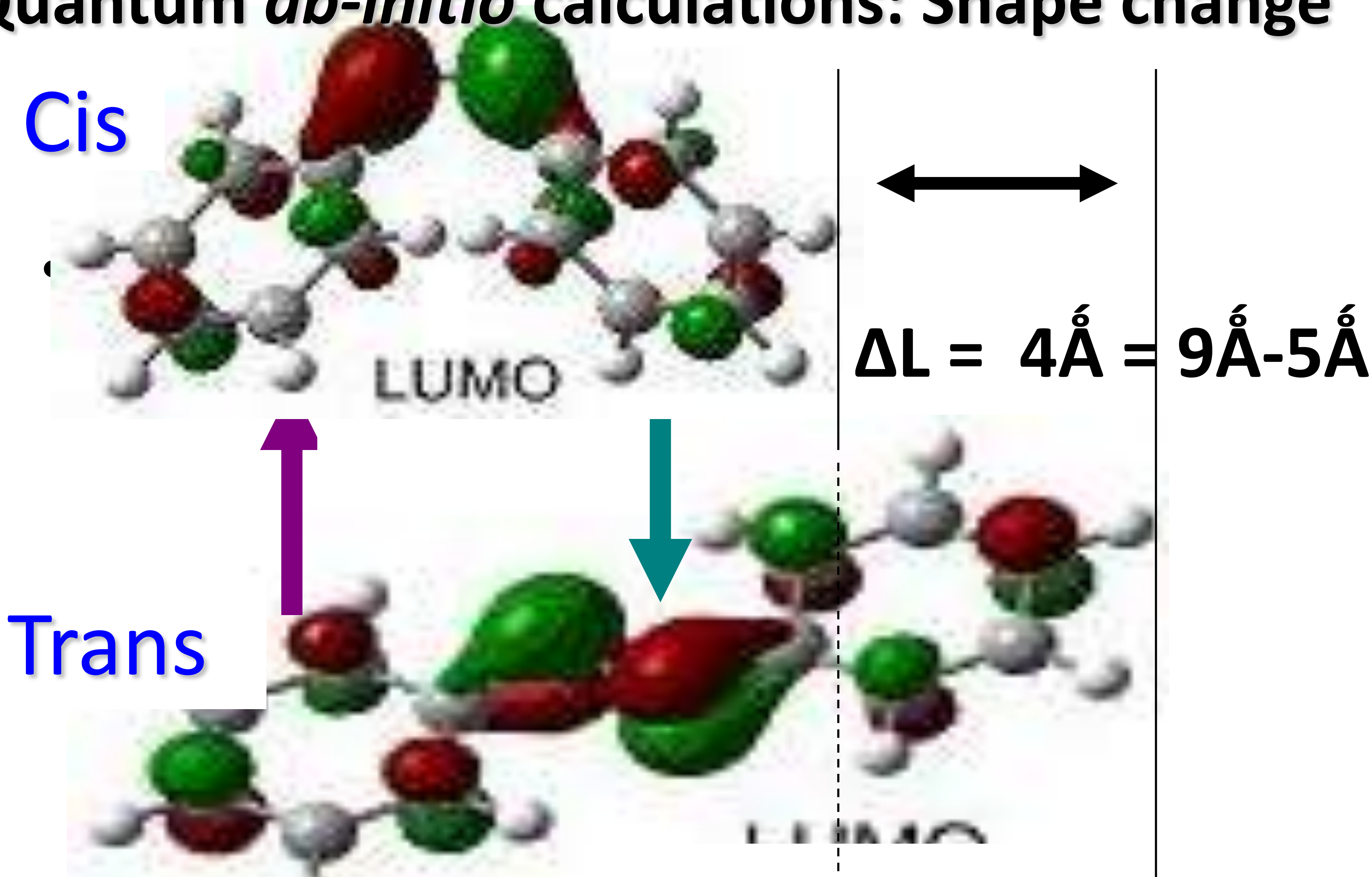
3. Upon de-excitation, some molecules are trapped in the *cis* conformation



Predicted by Boltzmann distribution

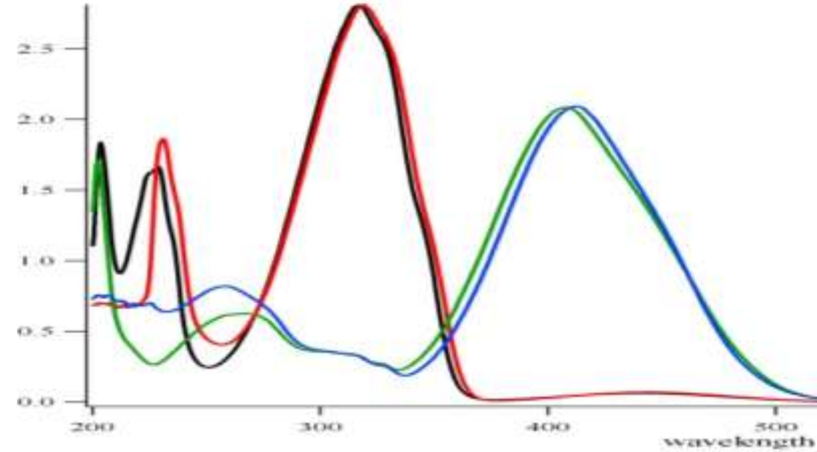
$$\frac{cis}{trans} = \exp\left(-\frac{E_{cis} - E_{trans}}{k_B T}\right)$$

Quantum *ab-initio* calculations: Shape change

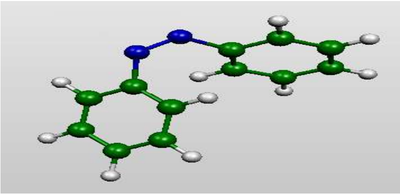


When irradiated by the correct wavelength of light or polarization chromophores in a matrix (polymer, crystal, or other) can cause movement of the matrix.

Cis-Trans Photoisomerization



- **Excitation Bands are Narrow**
  - **Minimizes ambient light as a control signal issue**



- **Without photo-isomerization, molecular movement is induced only by heating the polymer above its Tg,**
  - **material shape is stable, shape is reversible**
  - **these materials will work for cold aperture space optics and ground based adaptive optics**

Control- How It Works:
Orientation & PhotoIsomerization

- Deformation is produced along the polarization direction of linearly polarized light
- Polarized beams can exploit these traits to produce shape changes in 3 dimensions in a deformable mirror
- Color/polarization switch state

Use:

- to compensate for errors in primary mirror figure due to processing (or using a membrane)
- to damp out oscillations caused by telescope repointing and environmental perturbations
- to induce controlled deformations in AO systems used to correct wavefront aberrations induced by atmospheric propagation

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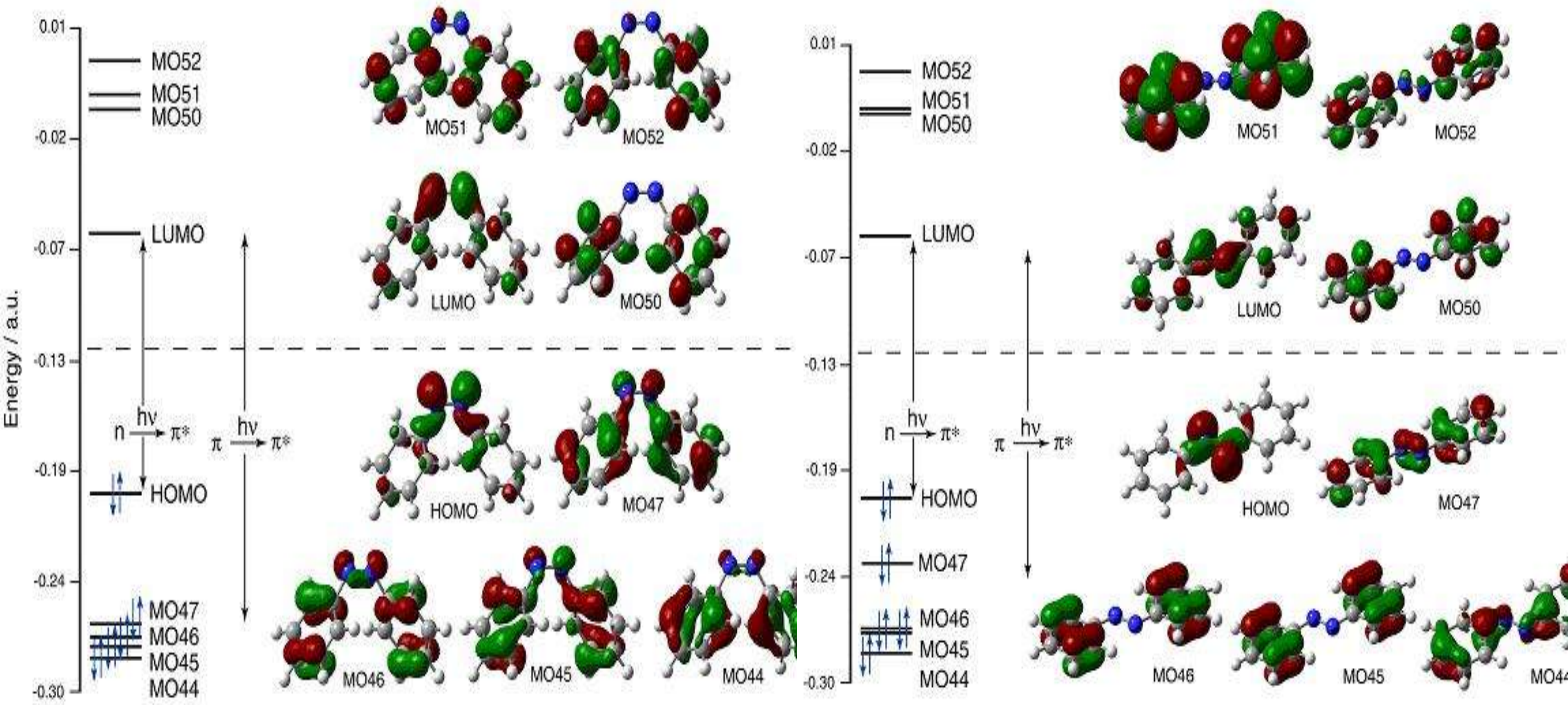
Density Functional Theory Calculations/Modeling

Using quantum *ab-initio* techniques obtained optimized geometries for both the cis and trans isomers. Trying to understand the potential energy surface and how it is perturbed to cause motion…

In both cases the highest occupied molecular orbital (HOMO) is a non-bonding orbital located on the nitrogen atoms and lowest unoccupied molecular orbital (LUMO) is a π * orbital located on the benzene rings.



Synthesis: proprietary content

Polymer Preparation

- Aligned polymer film
- Proprietary content

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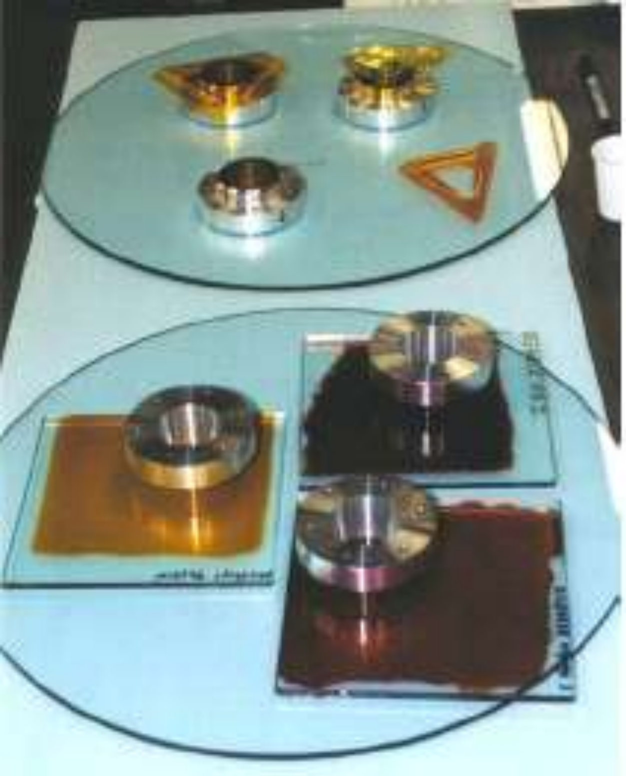

Make a mirror: Sample Mounting and Coating

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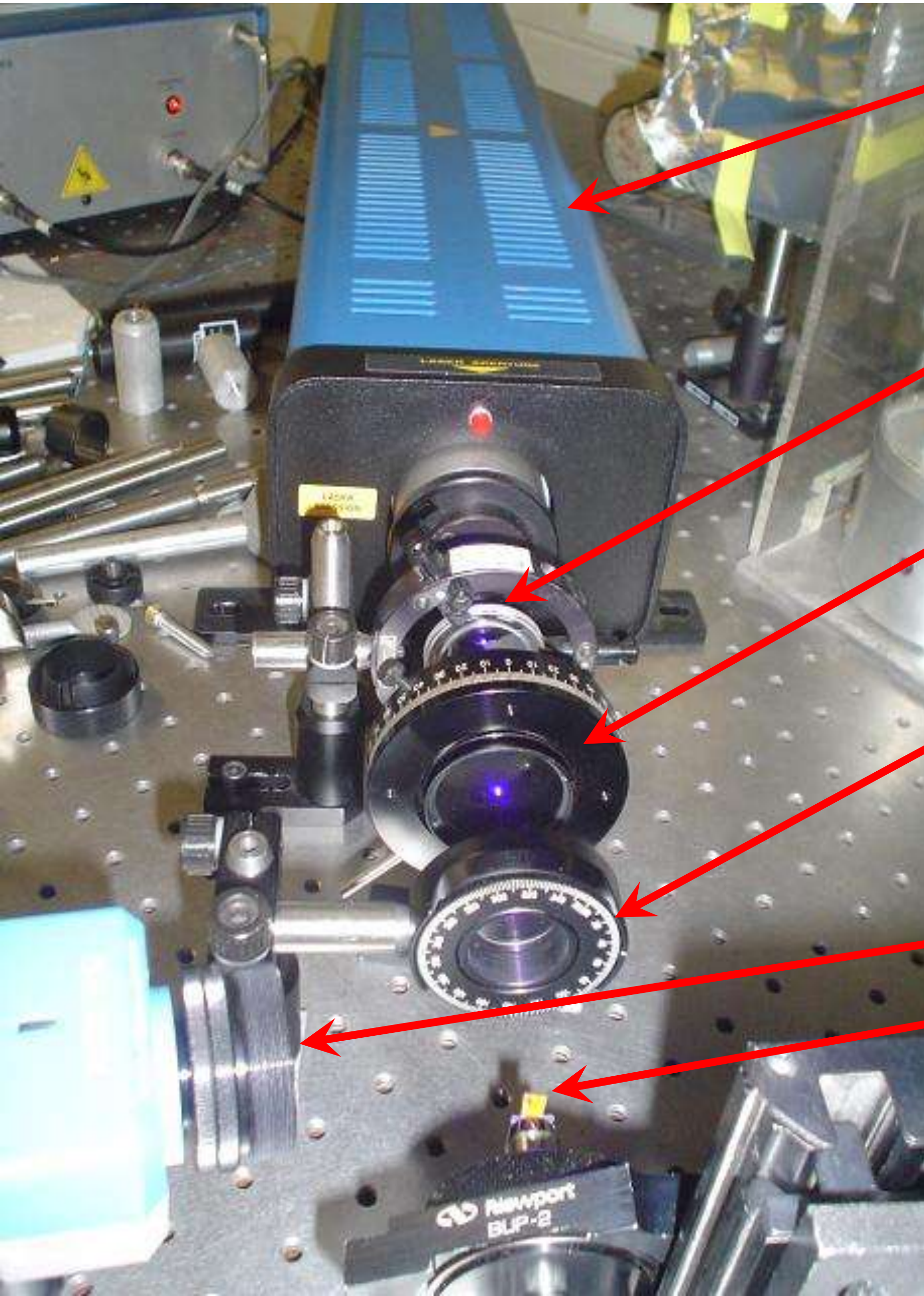
Proof of concept successful:



A Helium Cadmium laser was used to illuminate samples with linearly polarized Light.

Diverger reduced beam power so we would not melt samples.

Polarization analyzer ensured pure linearly polarized light

A ½ wave plate (optical retarder) was used to rotate the polarization direction of linear polarized light actuating the sample.

CMOS camera digitized the live video

Various test samples were illuminated

Realtime Result:

Best Material So Far

Proprietary content

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Functional Characteristics- Proof of Concept

Photonic Muscle Membrane Actuation with left IFA sample HeCd Laser (>3000 microns)

- **The laser-induced figure variations include;**
- **A set and forget polymer (<u>zero power consumption mode</u>)**
- **<u>Reversible bi-directional bending</u> of the polymer by switching the polarization of the beam in orthogonal directions**
- **<u>Large deformation range</u>, over 140° slope of deformation**
- **demonstrated <u>micron scale control</u>**
- **<u>High speed</u> of photoinduced deformations (1000 microns/second)**
- **Stability for weeks**

The large photomechanical effect is obtained in <u>thin polymers</u> (10-50 µm thick) and is <u>controlled with low power radiation</u> (~0.1 W/cm^2).

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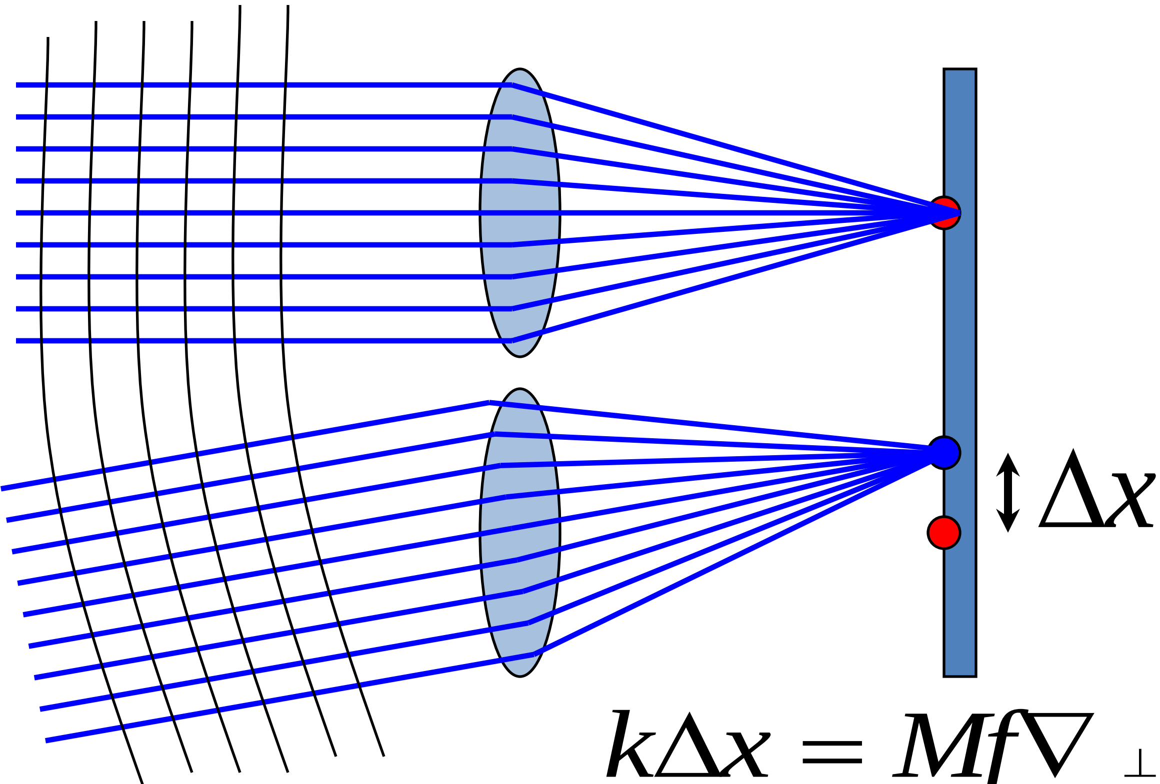
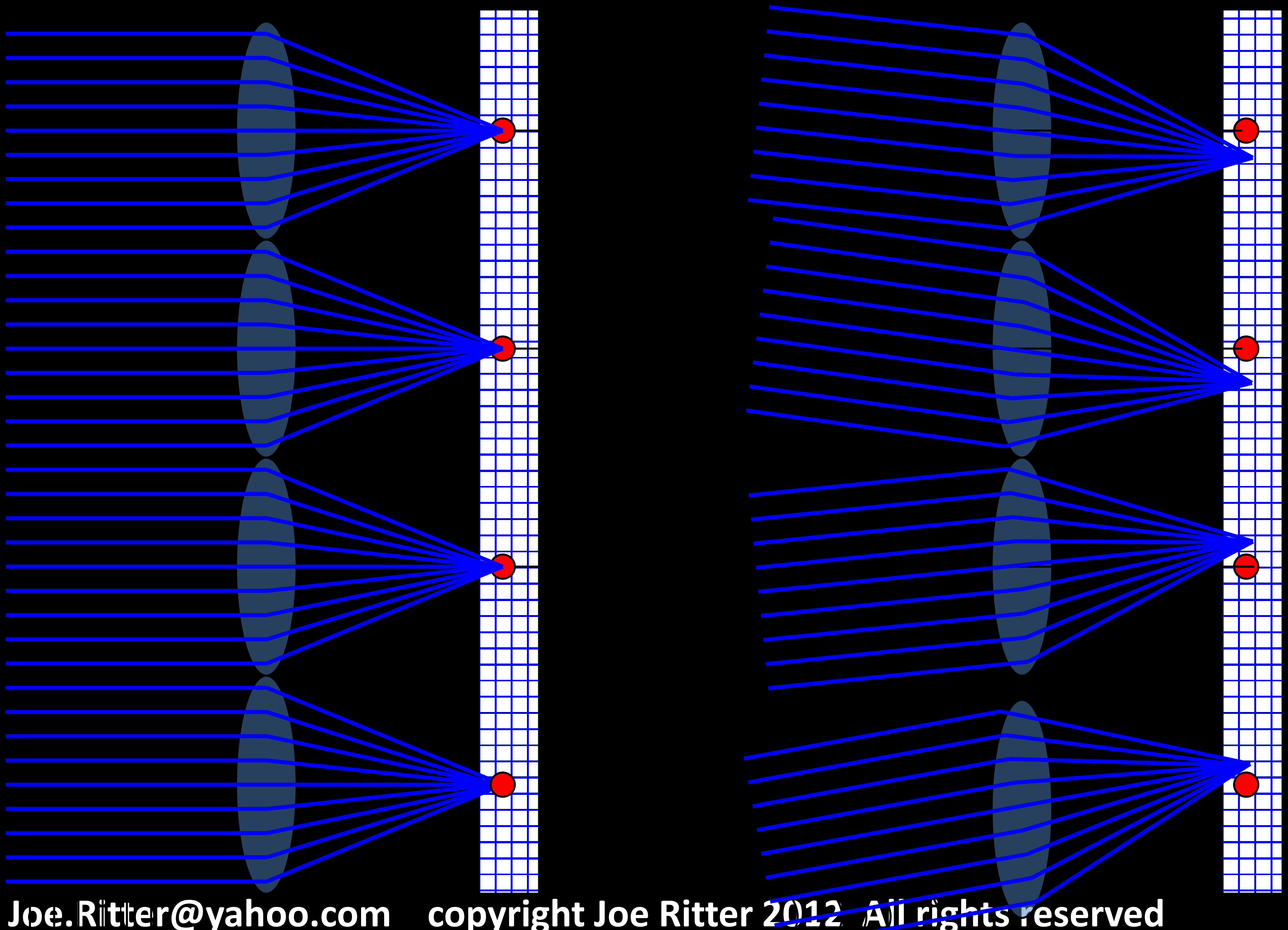
Shape needed for feedback: Shack Hartmann Sensor



$$k\Delta x = Mf\nabla_{\perp}\phi(x, y)$$

is the Relation between displacement of Hartmann spots and slope of wavefront where:

- ***k* = 2π/λ**
- ***Δx*** = lateral displacement of a subaperture image
- ***M* = *f*$_{\text{telescope}}$ / *f*$_{\text{collimator}}$** is the demagnification of the system
- ***f*** = focal length of the lenslets in the lenslet array
- **φ(x,y)** is the incoming wavefront



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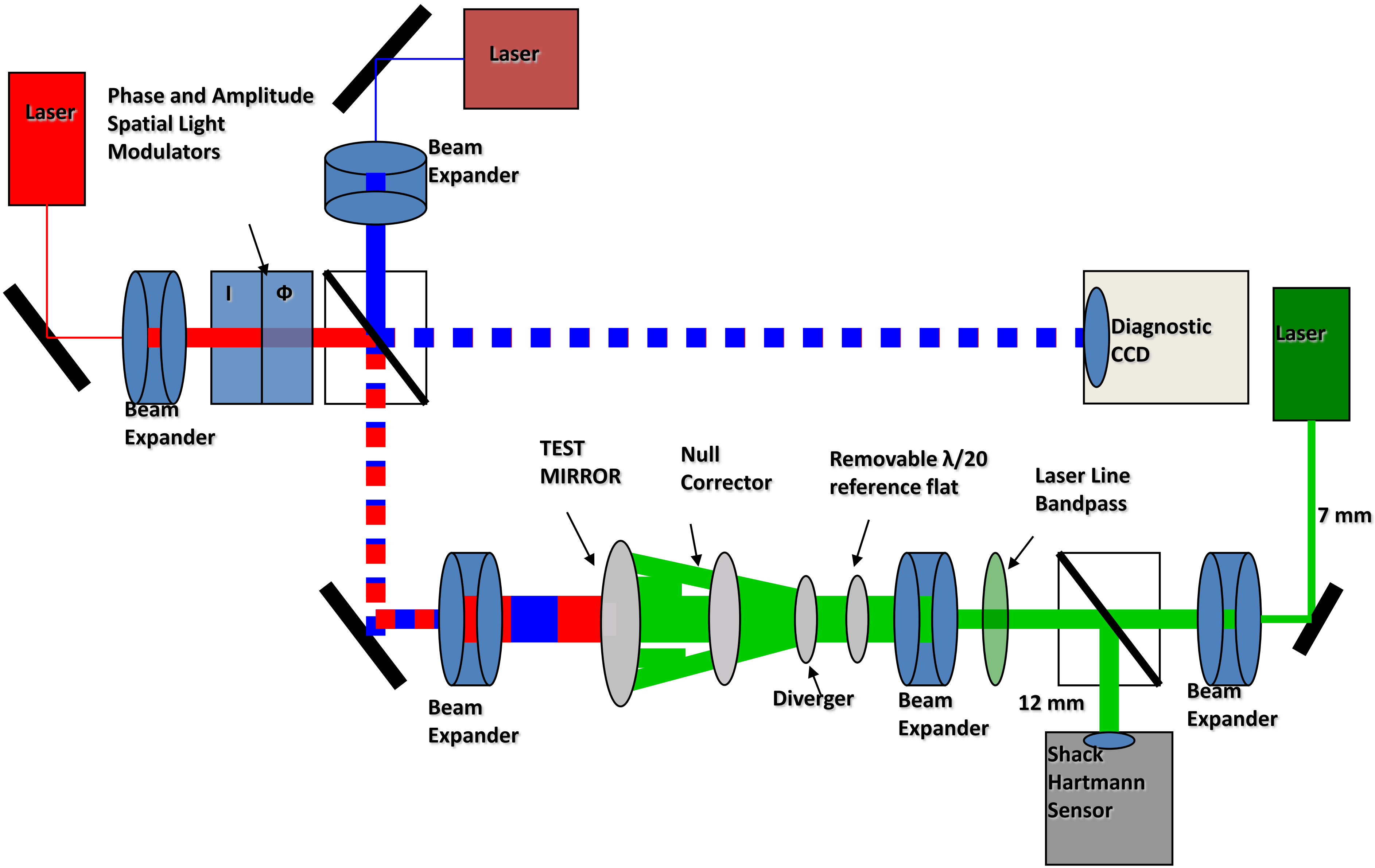
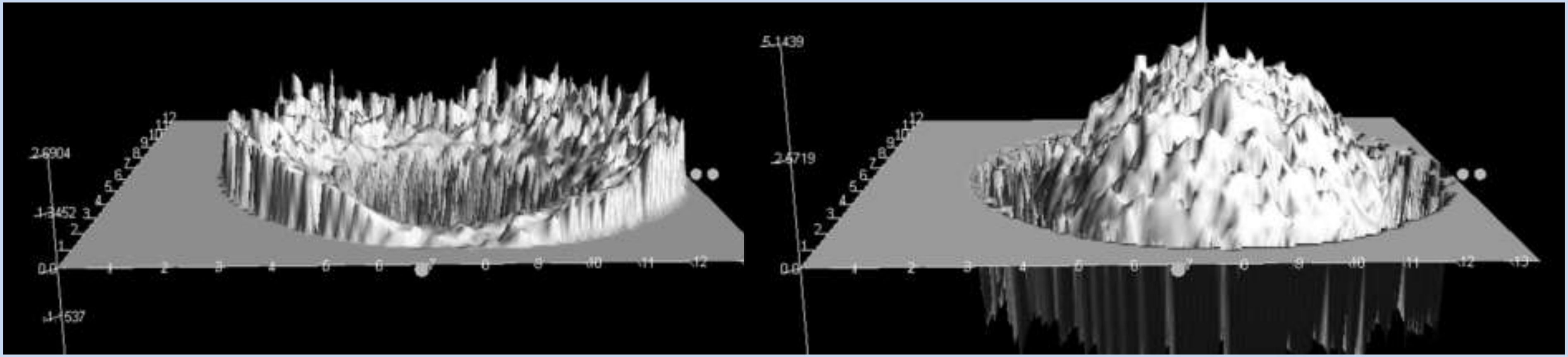
Old Mark 1 control system



Mirror Geometry Results:
Polarized Illumination Controls the Shape



Polarized   Unpolarized

In addition to large motion for control of dynamics we are also studying micron scale control authority

Here polarized illumination selectively flattens the sample when properly illuminated

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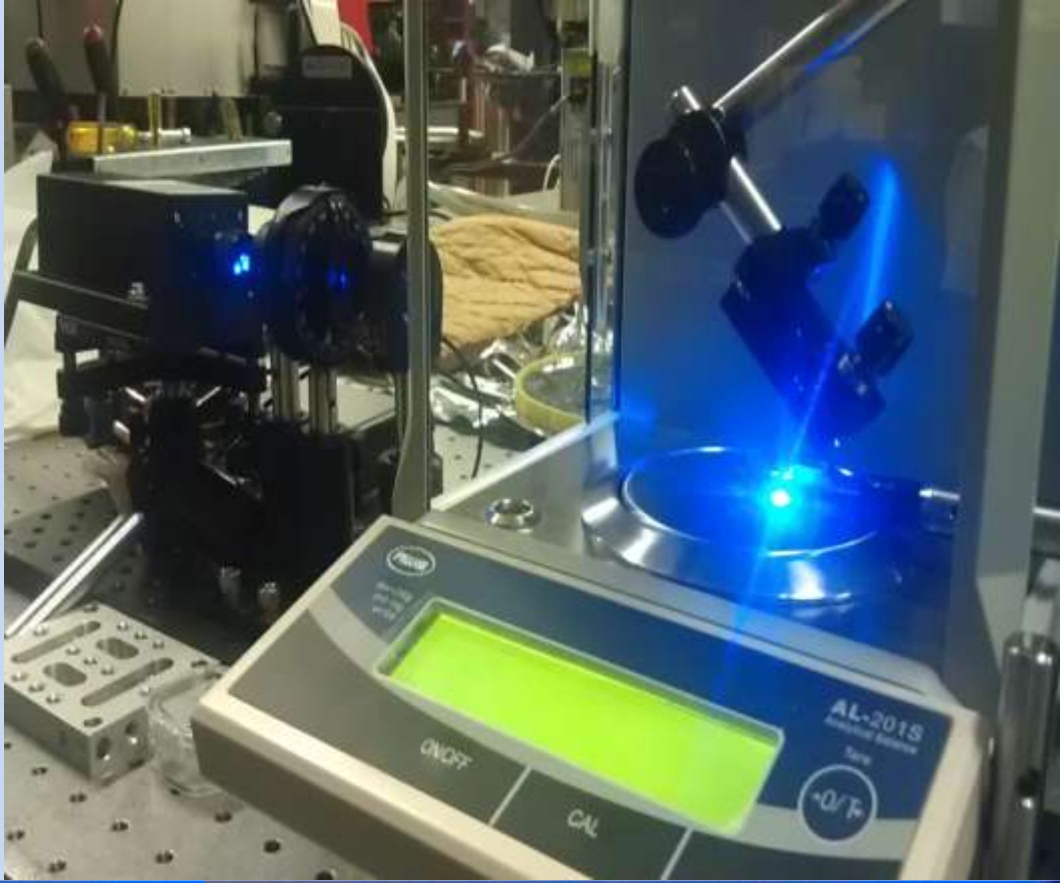
It has been suggested that (redacted Proprietary content**) would work for large ground based telescopes**

so I attempted a crude quick measurement.

Scale precision of 0.0001 grams

Viability?



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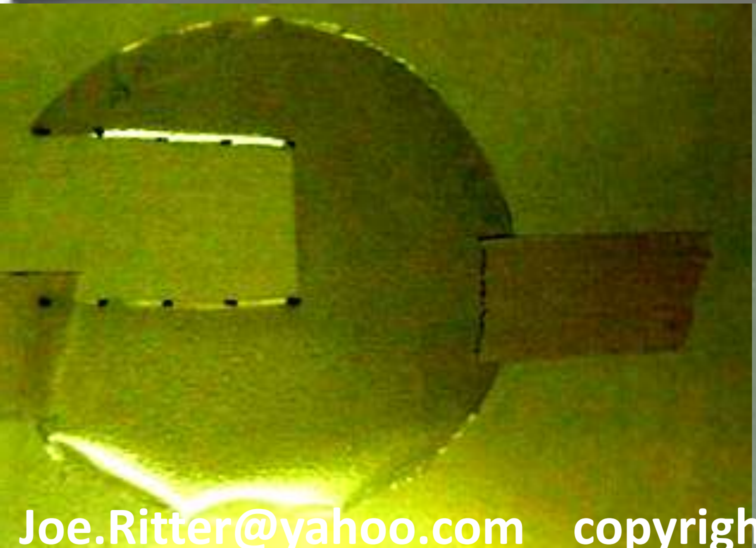
A new look at an old material



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Crude test of (Proprietary content) without molecular alignment

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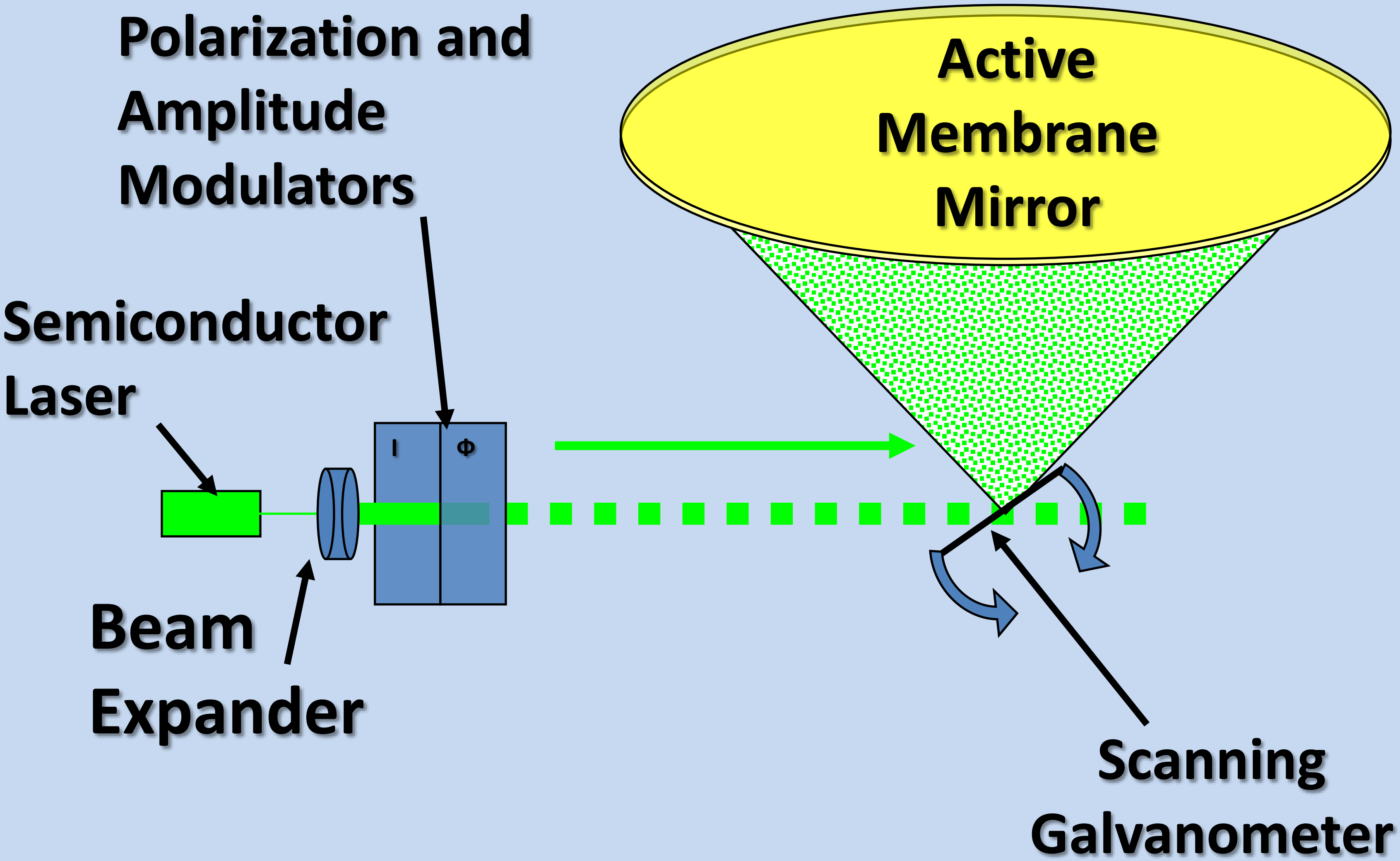
Large telescope: PMT Actuation System



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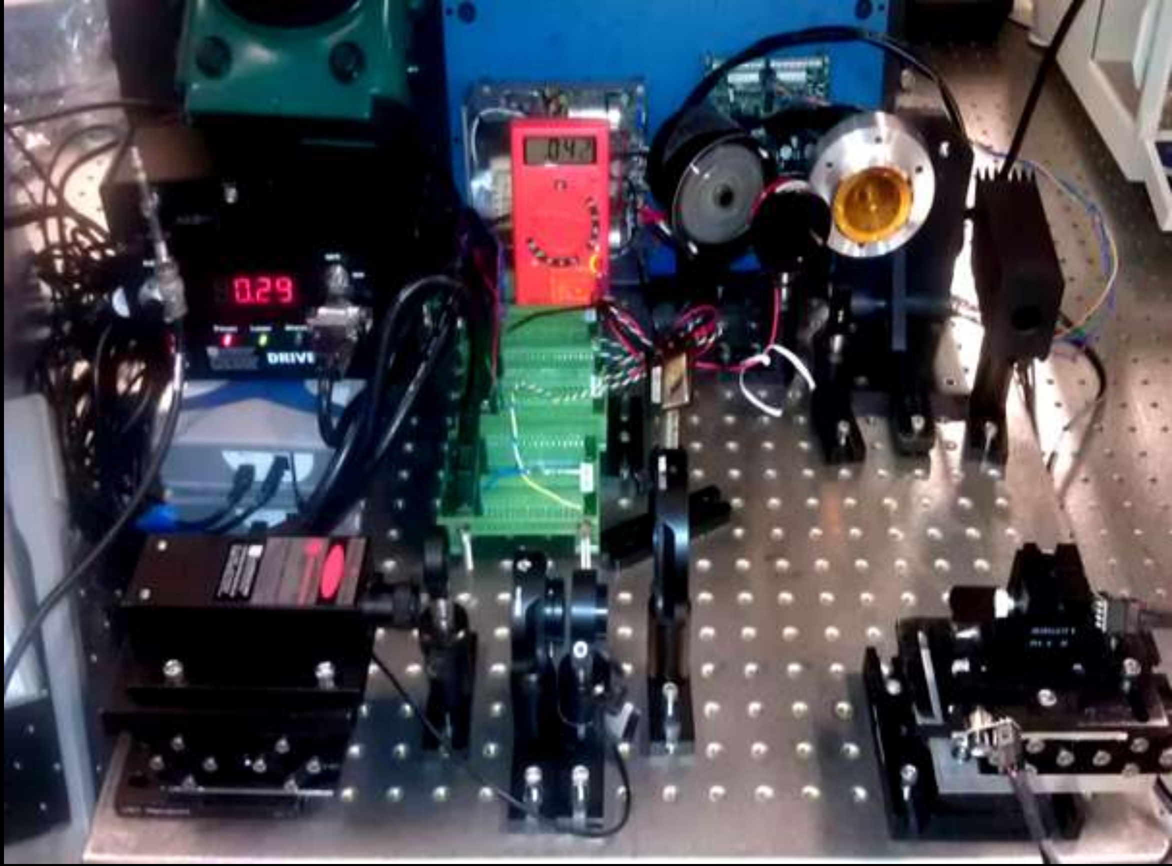
I needed a
Phase I PMTVDT

Versatile
Development
Test bed



computer control of
- **beam polarization**
- **beam power**
- **beam pointing (2 axis scan galvo)**
- **new custom software for controlling the above simultaneously**
- **low level and high level interfacing routines**
- **special software to generate calibration tables to control these parameters precisely**

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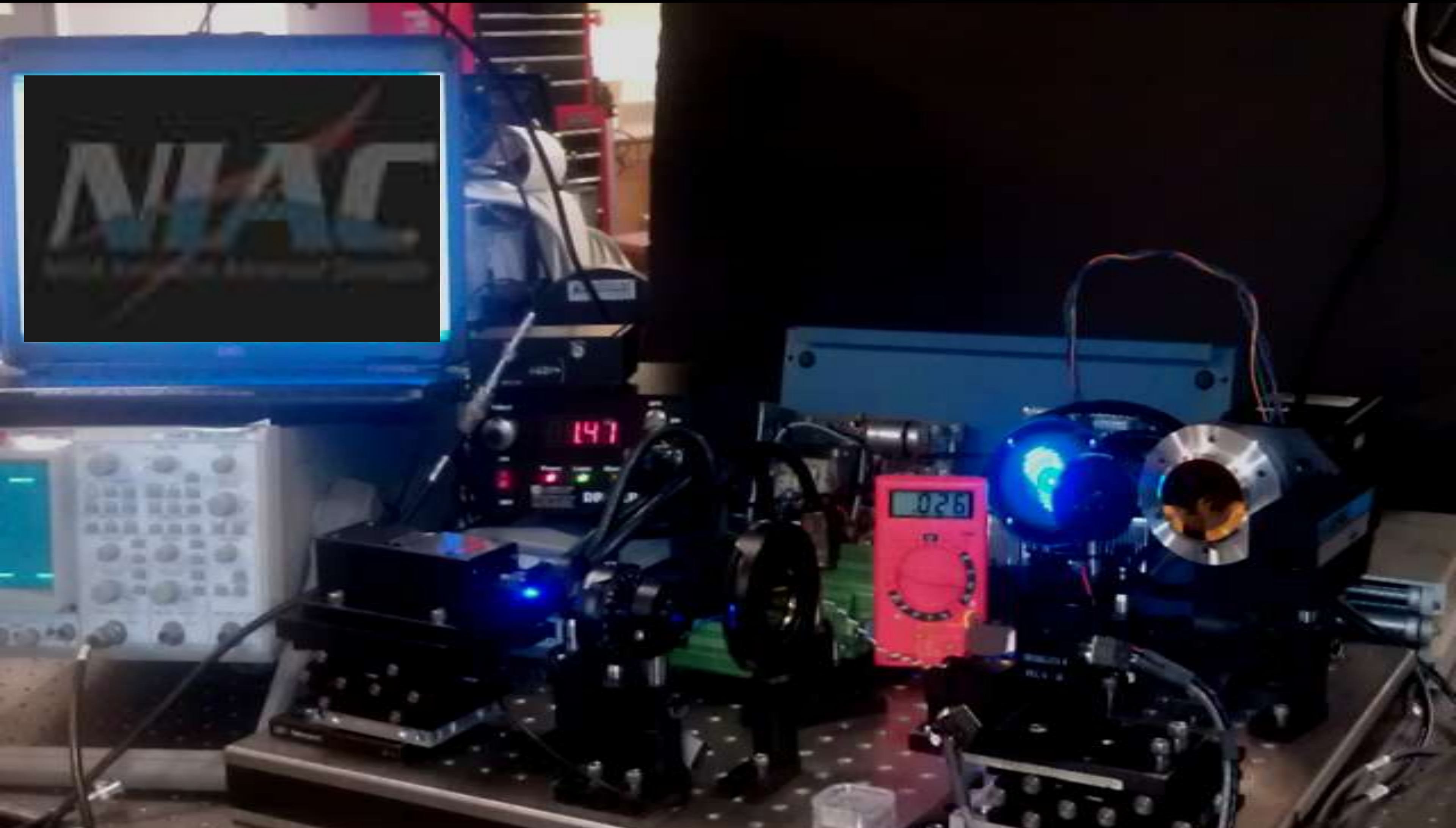
Since Jan report:
New Testbed, Mark 2 Control System



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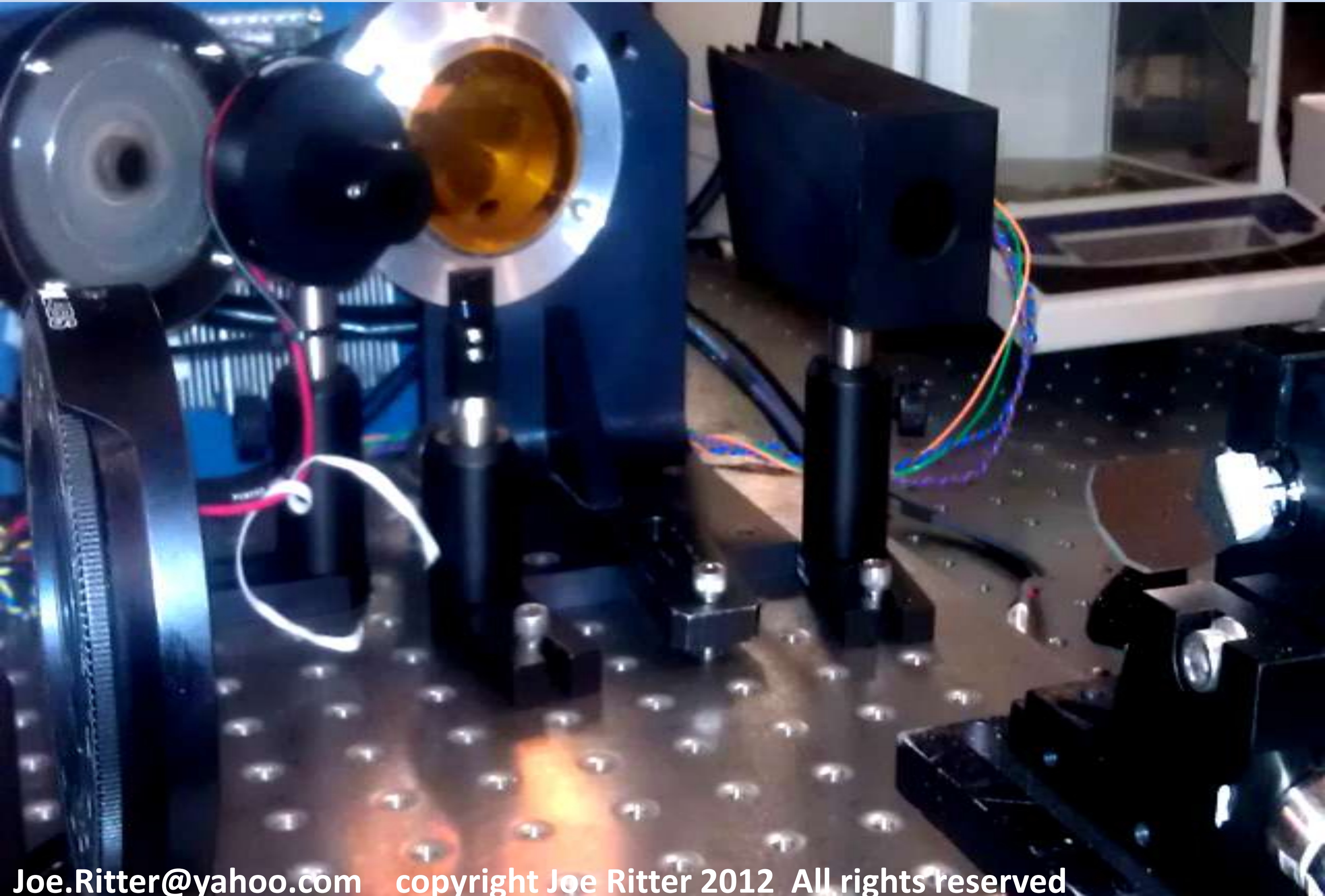
PMTVDT Target array



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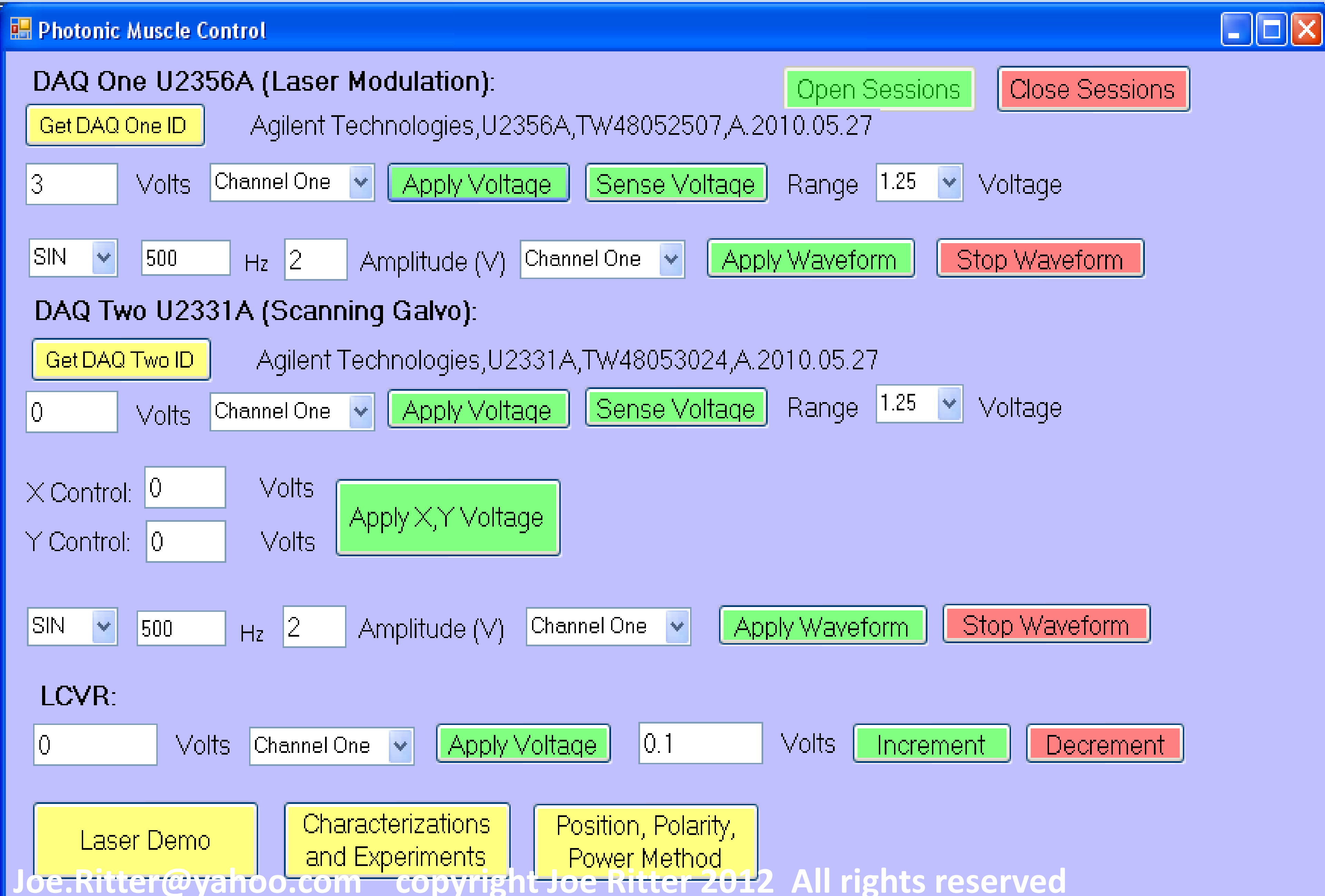
PMVDT Software Development-I/O



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Other Software Development

Shack Hartman feedback

Close the loop !

In progress

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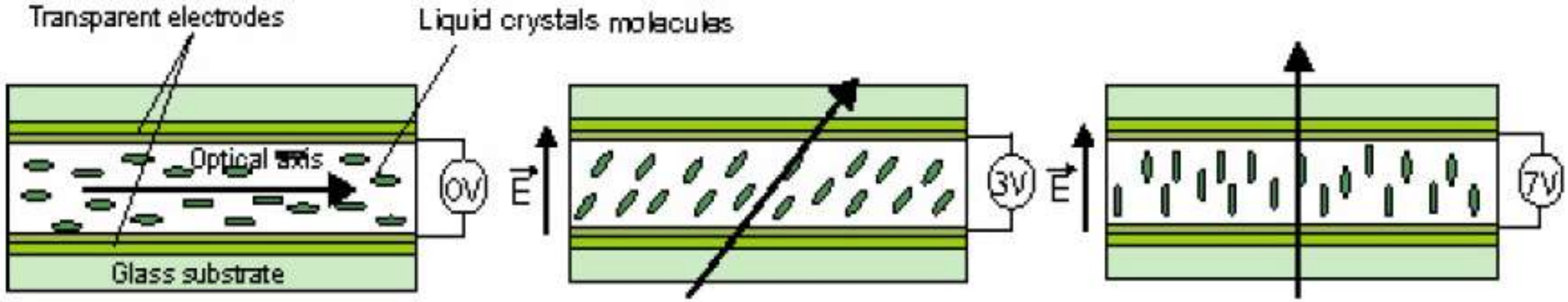
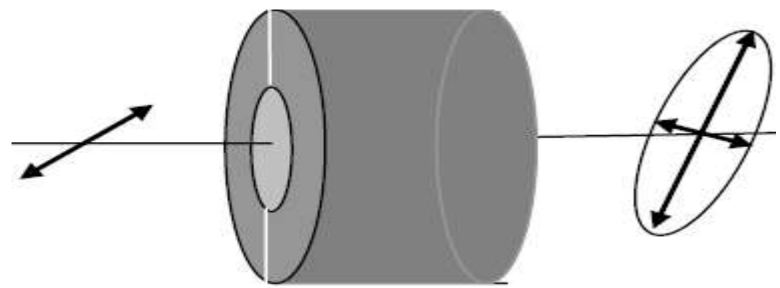
Polarization Modulation

Orientation of liquid crystals varies with applied AC square wave peak to peak voltage, rotates electric field (Polarization)





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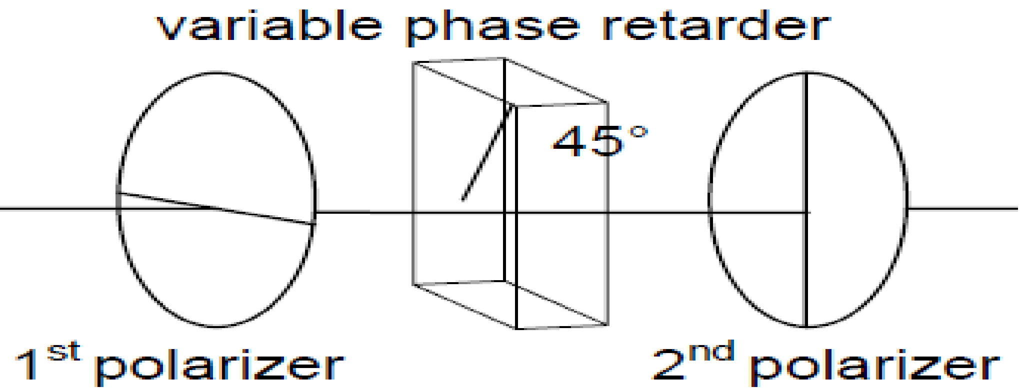
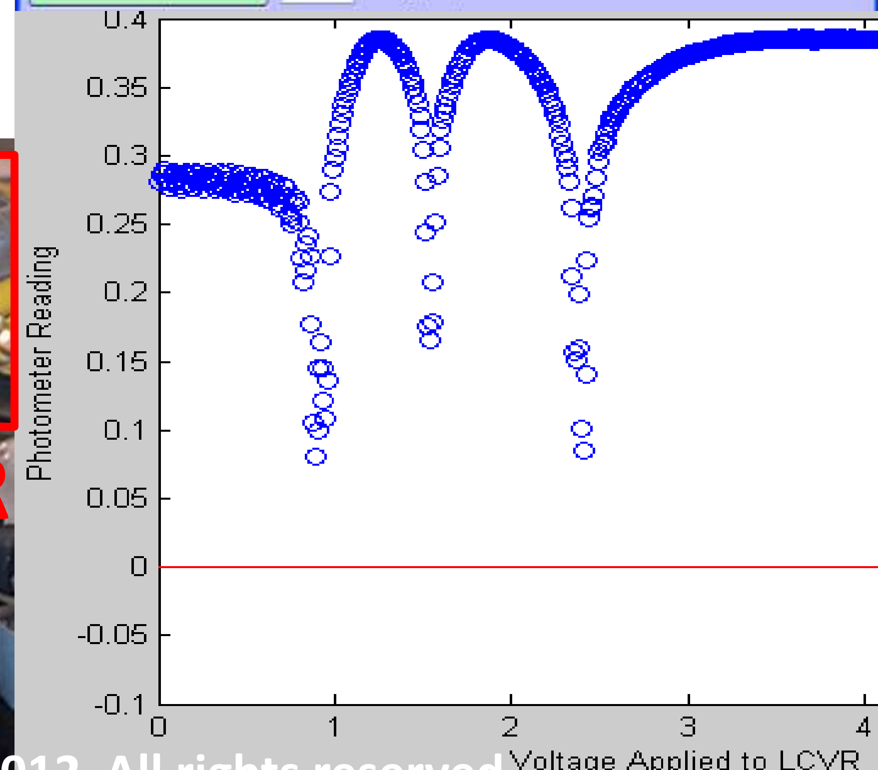
Polarization Modulation

Calibration software hardware and data

Calibration as variable attenuator now, next at 45 , then retardance δ is simply given by : $T(\delta)=T_{max}*(1-\cos(\delta))/2$





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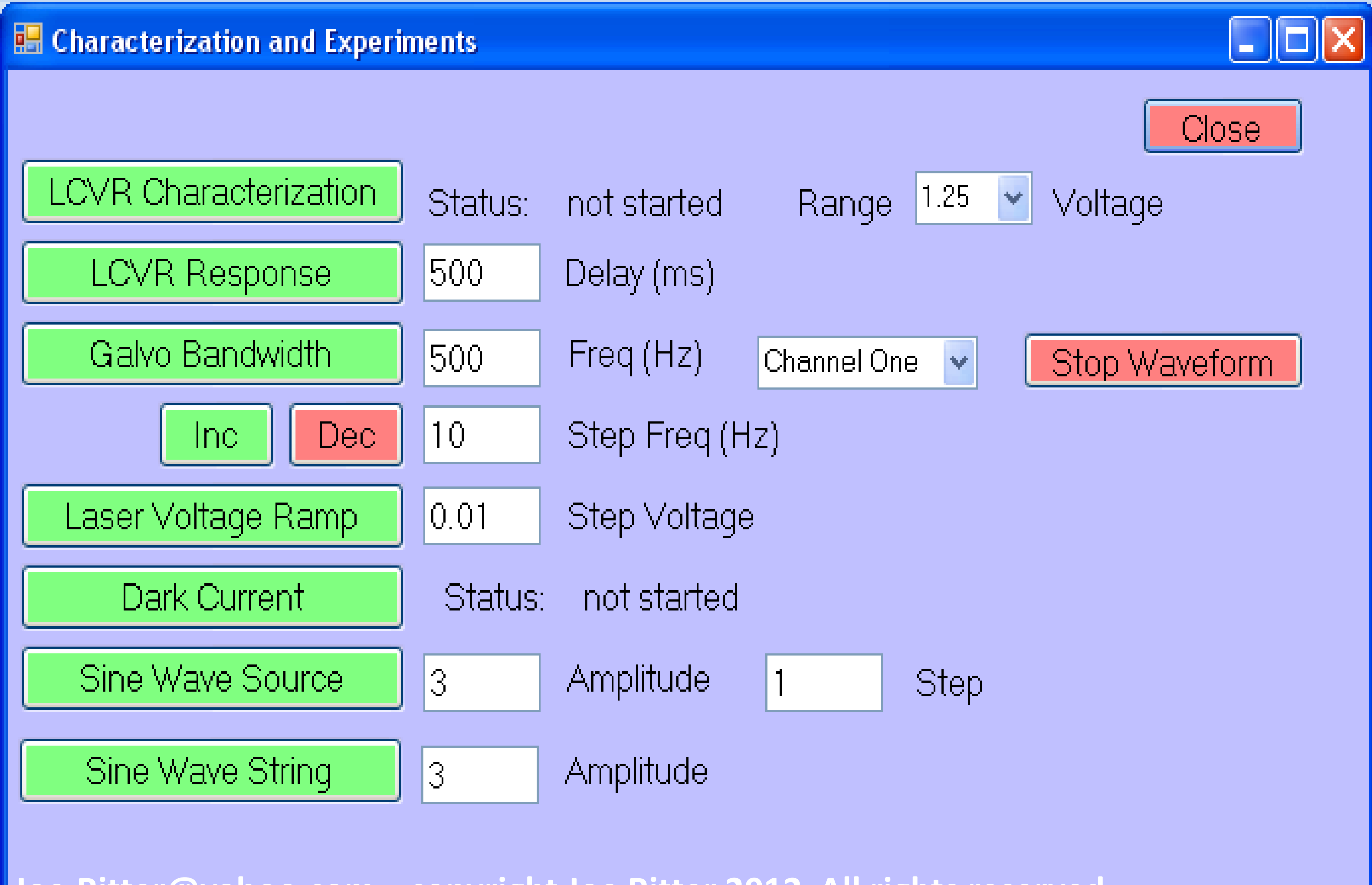
PMTVDT Software Development - Calibrations



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Polarization Modulation
Polarization rotation under computer control

Video

Modulation of the square wave P-P voltage rotates liquid crystal to rotate the photons electric field

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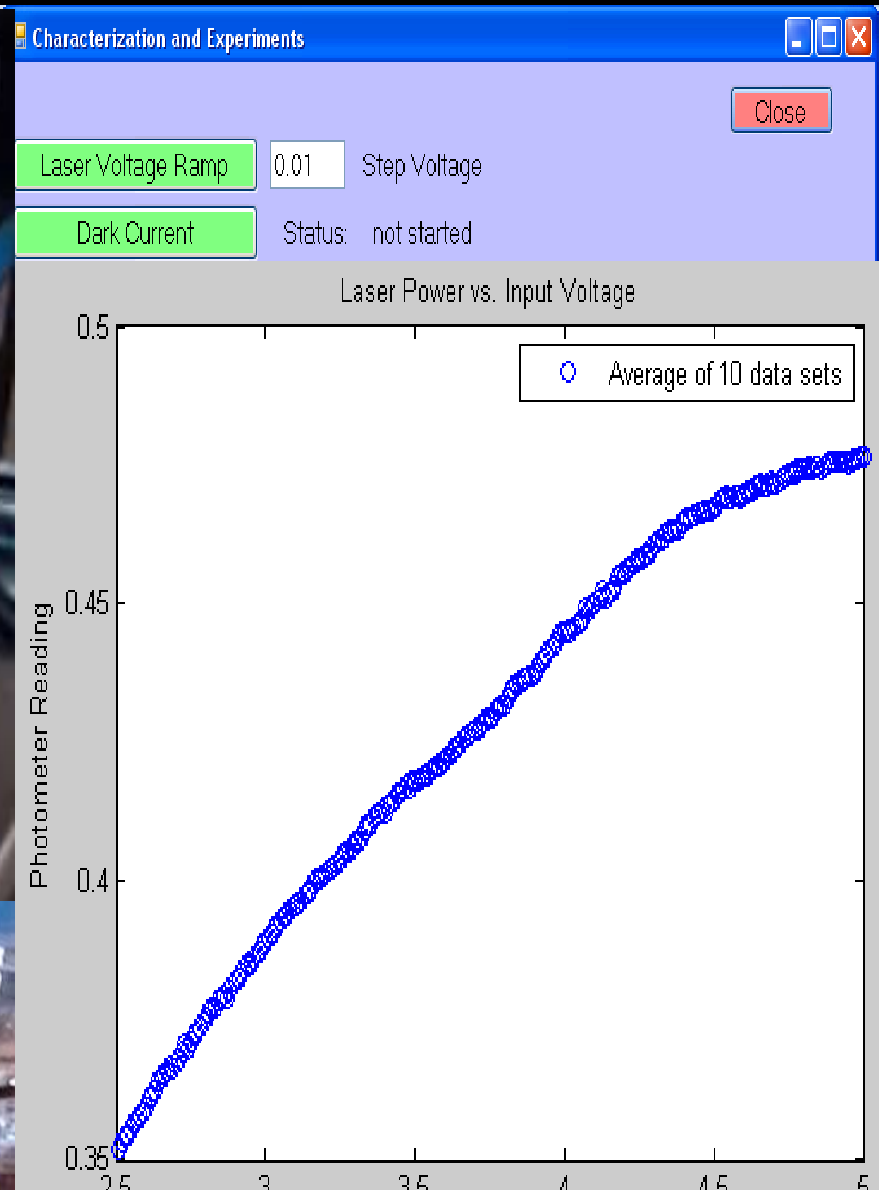
Laser Power Modulation
Calibration software hardware and data



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Laser Power Modulation Demo

Photometer

Video

Galvo

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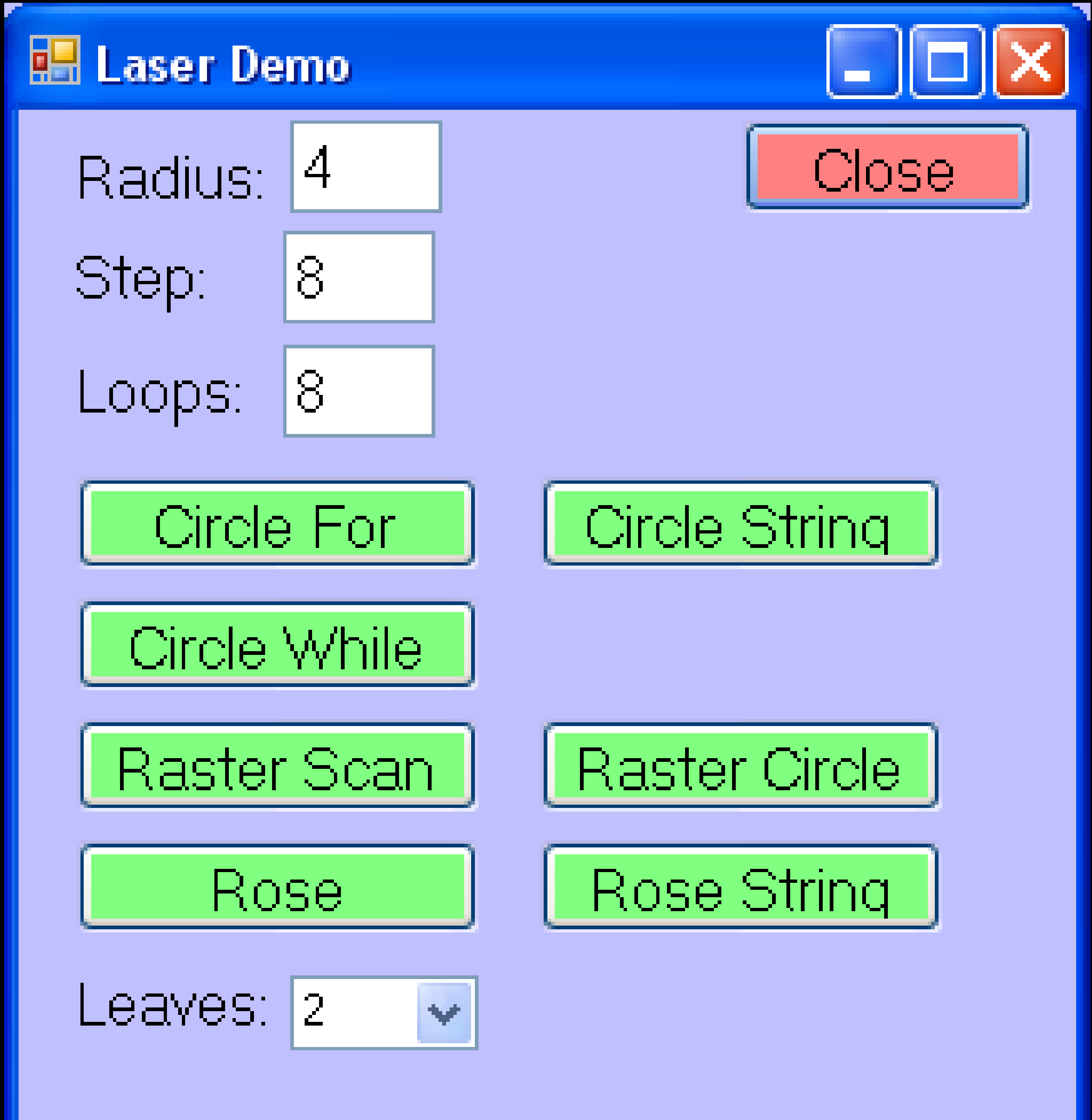
Scanning and Beam Control Modules



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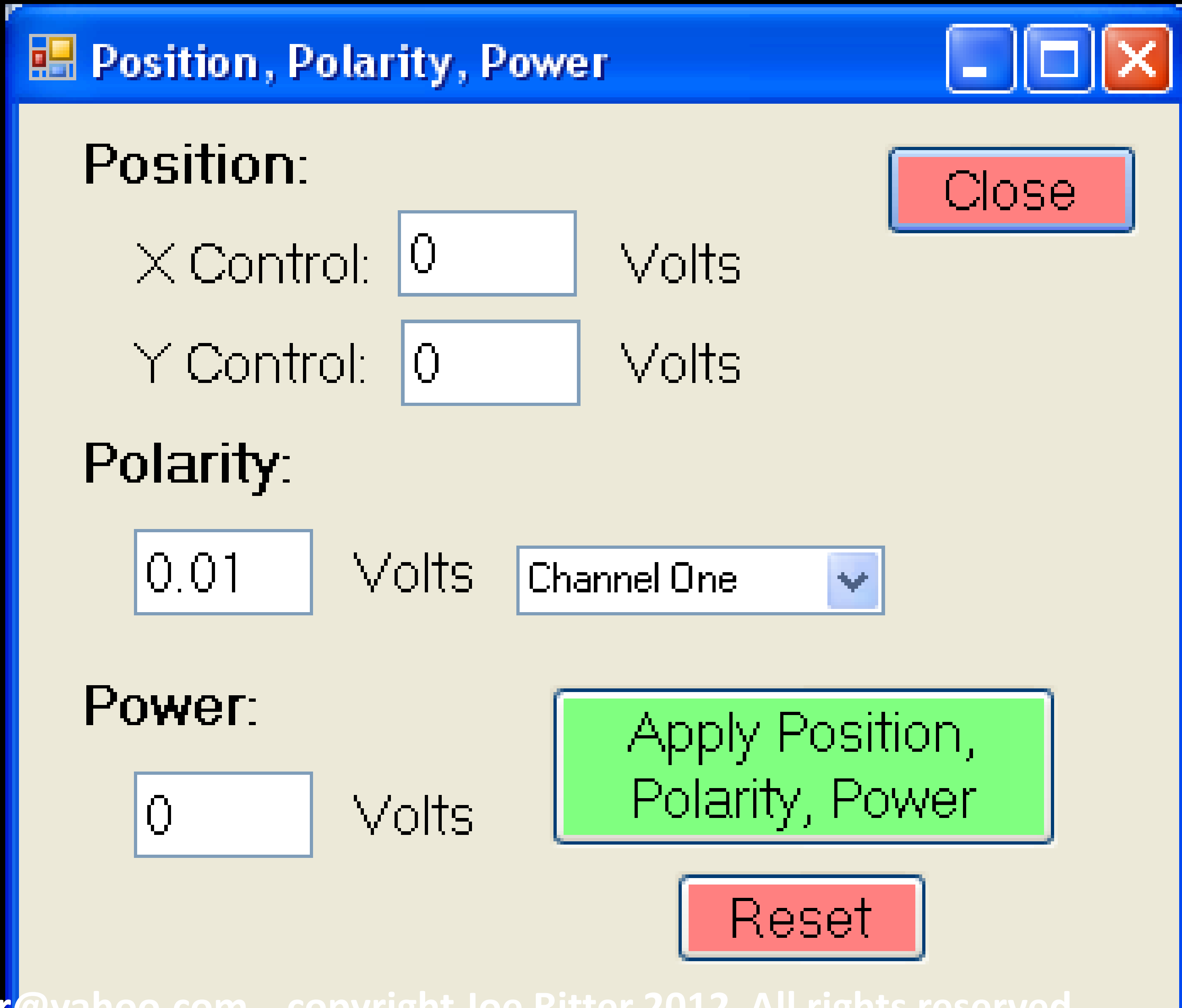
Base Multifunction Module



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Beam position

servo controlled ortho scanning galvanometer

Video

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Viability: Yes Realistic approach: Yes

- In my solution, mirrors are as thick as saran wrap, and every molecule is a laser powered nanoactuator.
- The concept has been demonstrated
- The substrates are 1/2000 the areal density of the Hubble Space Telescope!
- Mirror and spacecraft bus are all proportionally cheaper
- Inexpensive space telescopes are feasible!
- **Giant Mirrors and interferometers will be possible- think the size of a football field, not a human.**

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Next steps…

Require further study of

- Control authority
- Control system loop
- O_1 and UV resistance
- Scaling
- Complex powered optics
- Design trade-space of actual design-Off axis?
- Packing ratio
- 0.5, 1, 2 4, 8 meters
- Funding venues
- Launch

Programmatic benefits

- Cost
- Risk mitigation
- Resolution
- Cheaper than TMT

Mission contexts

- Any large aperture
- Cheap NIAC based NST
- SIM TPF etc.
- Multi use system-….

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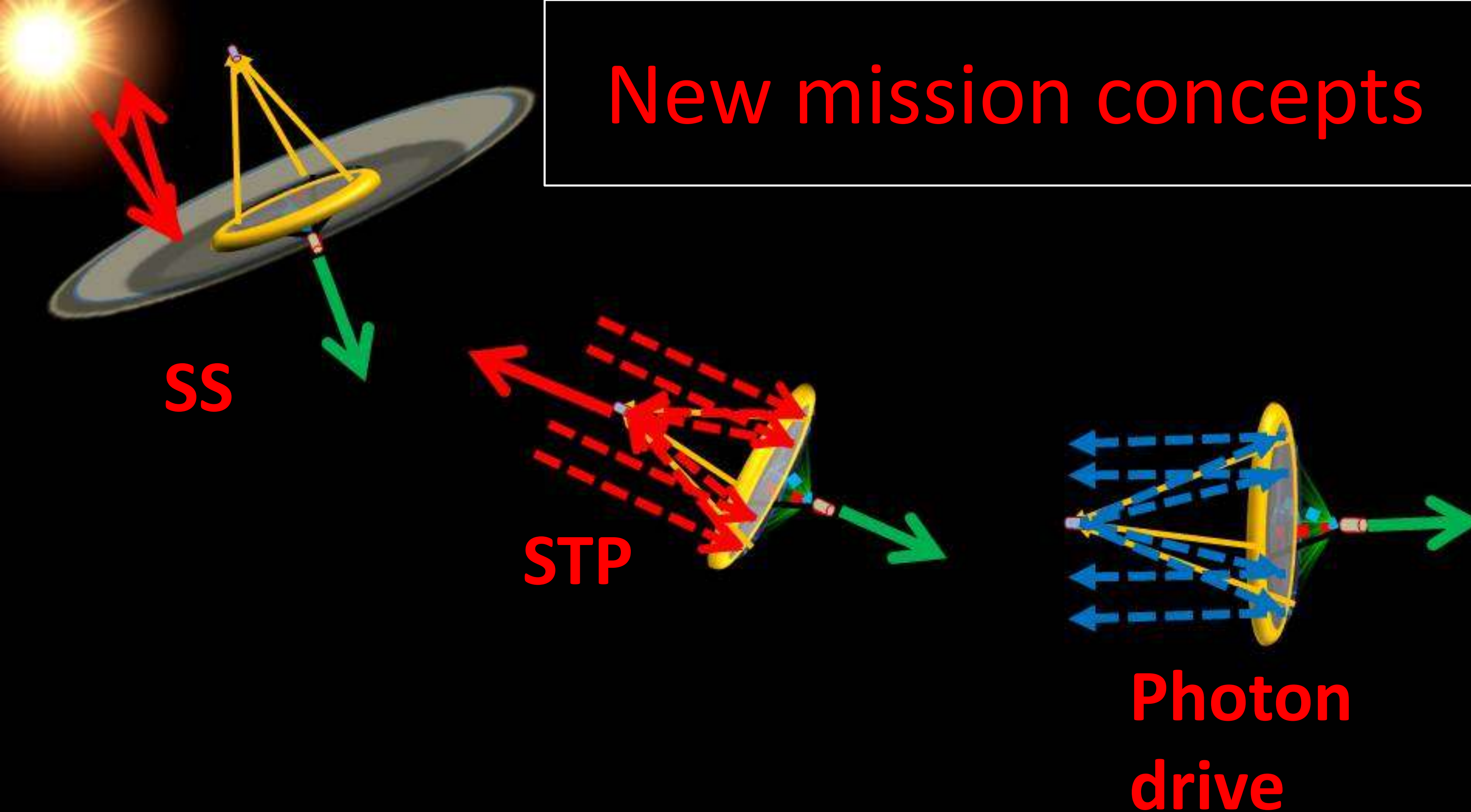
New mission concepts



Multimode propulsion+ Imaging,
Power generation, LD Comm dish…

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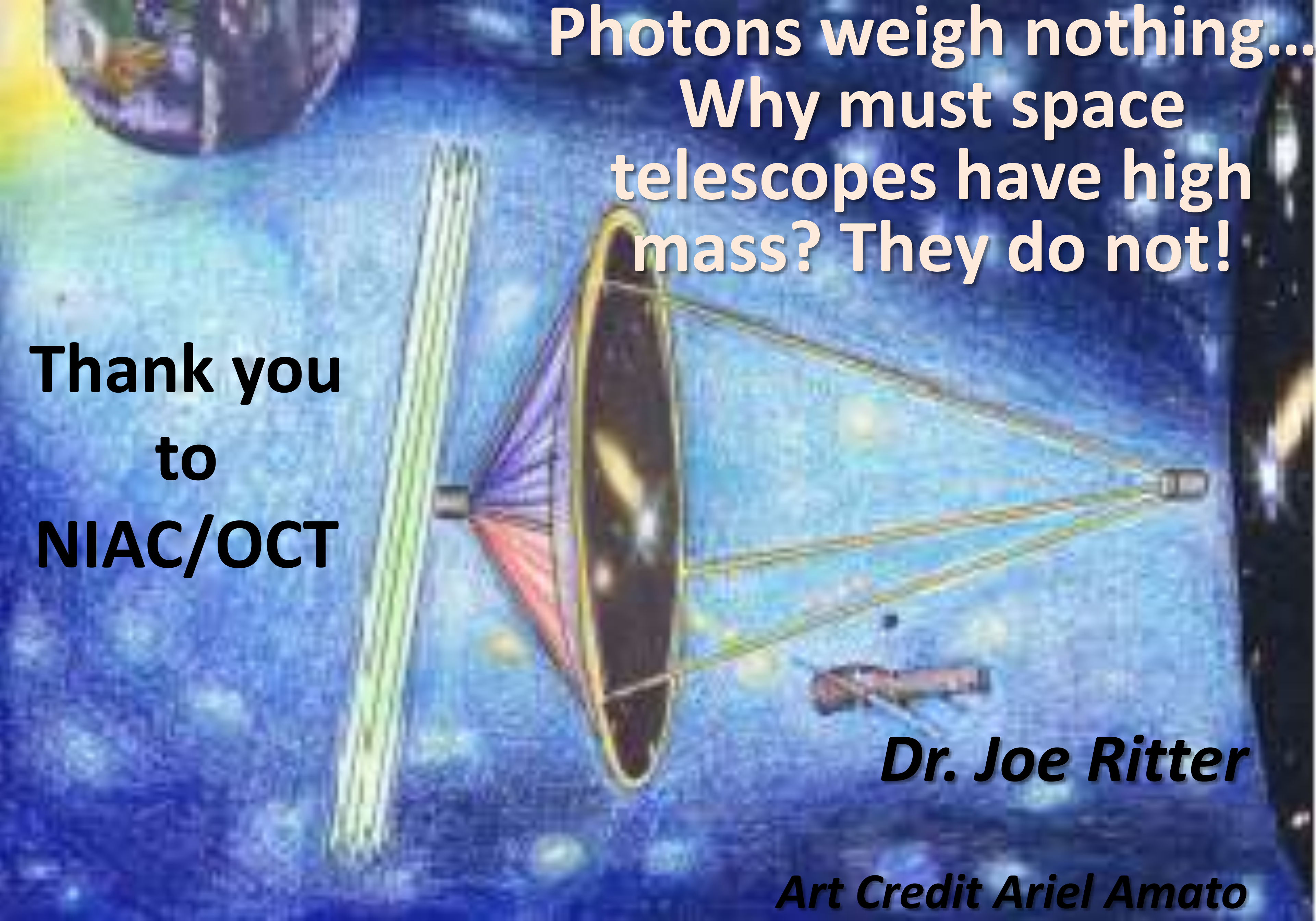
We are ready to accelerate development now

One Goal: Make a 6 meter diameter *active* mirror that Weighs 6 kilograms not 600 kilos

Costing <1% of current technology

Photons weigh nothing… Why must space telescopes have high mass? They do not!



Thank you to NIAC/OCT

Dr. Joe Ritter

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